SIDGWICK & JACKSON

1971 YEARBOOK OF ASTRONOMY

EDITED BY PATRICK MOORE

1971 Yearbook of Astronomy

Edited by **PATRICK MOORE**

The *Yearbook of Astronomy* has now established itself as an invaluable handbook for astronomers, and the *1971 Yearbook* follows the popular tradition of earlier editions. Here is the information which any one interested in astronomy will find indispensable: monthly star charts, special events during the year, the position of the planets, eclipses, occultations, comets, and meteors.

Also included are articles on amateur opportunities in contemporary lunar research, the 1969 space-probes to Venus and Mars, and positional astronomy.

Patrick Moore, the editor, has contributed articles on test objects, and recent developments in astronomy.

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Contents

Editorial

The present *Yearbook* follows the established pattern, with notes for 1971, articles of all kinds, and the usual "miscellanea". Again Dr J. G. Porter's contributions have been invaluable, and it is he who has provided all of Part I apart from the monthly comments. Dr Porter relinquished the Editorship of the *Yearbooks* seven years ago, but without his continued help it would be difficult or even impossible to maintain the standard that he set.

Thanks are due to all our contributors, some of whom have written for us before while others are presenting their first articles. Lawrence Clarke has provided the line drawings, as on previous occasions.

Last but by no means least, I must again express my most sincere thanks to J. S. Knapp-Fisher and his colleagues at Messrs Sidgwick and Jackson; and, for the American edition, equally to Eric Swenson and all those at Messrs W. W. Norton and Co.

PATRICK MOORE

Selsey, 1970

Preface

New readers will find that all the information in this *Yearbook* is given in diagrammatic or descriptive form; the positions of the planets may easily be found on the specially designed star charts, while the monthly notes describe the movements of the planets, and give details of other astronomical phenomena that may be observed from these latitudes. The reader who needs more detailed information will find *Norton's Star Atlas* (Gall and Inglis, 25*s*) invaluable, while more precise positions of the planets and their satellites, together with predictions of occultations, meteor showers and periodic comets may be found in the *Handbook* of the British Astronomical Association. A somewhat similar publication is the *Observer's Handbook* of the Royal Astronomical Society of Canada, and readers will also find details of forthcoming events given in the American *Sky and Telescope* which also publishes complete details of all occultations visible in North America.

Important Note

The star charts are drawn, and the notes are, in general, designed for use in latitude 52 degrees north, but may be used without alteration throughout the British Isles, and (except in the case of eclipses and occultations) in other countries of similar north latitude.

The times given on the star charts and in the Monthly Notes are generally given as local times, using the 24-hour clock, the day beginning at midnight. Ignoring small differences of longitude, this local time may be taken as Greenwich Mean Time (G.M.T.) in the British Isles, or as the appropriate Standard Time in other Time Zones. If Summer Time is in use, the clocks

will have been advanced by one hour, and this hour must be subtracted from the clock time to give local time.

Readers in Great Britain should note that permanent Summer Time may still be in force. Although this is called 'British Standard Time' it is not, in fact, a true astronomical Standard Time, and *one hour should be deducted from B.S.T. to give G.M.T.* The times of a few events are given in G.M.T., but this is clearly stated in all such cases.

Index to Articles in Previous *Yearbooks*

PART ONE

Events of 1971

Monthly Charts and Astronomical Phenomena

Notes on the Star Charts

The stars, together with the Sun, Moon and planets, seem to be set on the surface of the celestial sphere, which appears to rotate about the Earth from east to west. Since it is impossible to represent a curved surface accurately on a plane, any kind of star map is bound to contain some form of distortion. But it is well known that the eye can endure some kinds of distortion better than others, and it is particularly true that the eye is most sensitive to deviations from the vertical and horizontal. For this reason the star charts given in this volume on pages 20 to 45 have been designed to give a true representation of vertical and horizontal lines, whatever may be the resulting distortion in the shape of a constellation figure. It will be found that the amount of distortion is, in general, quite small, and is only obvious in the case of large constellations such as Leo and Pegasus, when these appear at the top of the charts, and so are drawn out sideways.

The charts show all stars down to the fourth magnitude, together with a number of fainter stars which are necessary to define the shape of a constellation. There is no standard system for representing the outlines of the constellations, and triangles and other simple figures have been used to give outlines which are easy to follow with the naked eye. The names of the constellations are given, together with the proper names of the brighter stars. The apparent magnitudes of the stars are indicated roughly by using four different sizes of dots, the larger dots representing the bright stars.

There are four such charts at each opening, and these give a complete coverage of the sky up to an altitude of $62\frac{1}{2}$ degrees; there are twelve such sets to cover the entire year. The upper two charts show the southern sky, south being at the centre; the

coverage is 200 degrees in azimuth, from a little north of east (top left) to a little north of west (top right). The two lower charts show the northern sky, from a little south of west (lower left) to a little south of east (lower right). There is thus an overlap east and west.

The charts have been drawn for a latitude of 52 degrees, but may be taken without appreciable error to apply to all parts of the British Isles. They will also be equally suitable for any other part of the world having a north latitude of about 52 degrees—e.g. parts of Europe and Asia, and Canada. In such cases the times given must be taken as local time, and not G.M.T., which applies only to the British Isles.

Because the sidereal day is shorter than the solar day, the stars appear to rise and set about four minutes earlier each day, which amounts to two hours in a month. Hence the twelve sets of charts are sufficient to give the appearance of the sky throughout the day at intervals of two hours, or at the same time of night at monthly intervals throughout the year. The actual range of dates and times when the stars on the charts are visible is indicated at the top of each page. This information is summarized in the following table, which gives the number of the star chart to be used for any given month and time.

G.M.T.	16^h	18^h	20^h	22^h	0^h	2^h	4^h	6^h
January	10	11	12	1	2	3	4	5
February		12	1	2	3	4	5	6
March			2	3	4	5	6	
April			3	4	5	6		
May			4	5	6	7		
June			5	6	7			
July			6	7	8	9		
August			7	8	9	10	11	
September		7	8	9	10	11	12	
October		8	9	10	11	12	1	
November	8	9	10	11	12	1	2	3
December	9	10	11	12	1	2	3	4

The charts are drawn to scale, and estimates of altitude and azimuth may be made from them. These values will necessarily be mere approximations, since no observer will be exactly on the meridian of Greenwich at 52 degrees latitude, but they will generally serve for the identification of stars and planets. The horizontal measurements, marked at every ten degrees, give the azimuths (or true bearings) measured from the north round through east (90 degrees), south (180 degrees), and west (270 degrees). The vertical measurements, similarly marked, give the altitudes of the stars up to $62\frac{1}{2}$ degrees.

The ecliptic is drawn as a broken line on which the longitude is marked at every ten degrees; the positions of the planets at any time are then easily found by reference to the table immediately following the star charts on page 46.

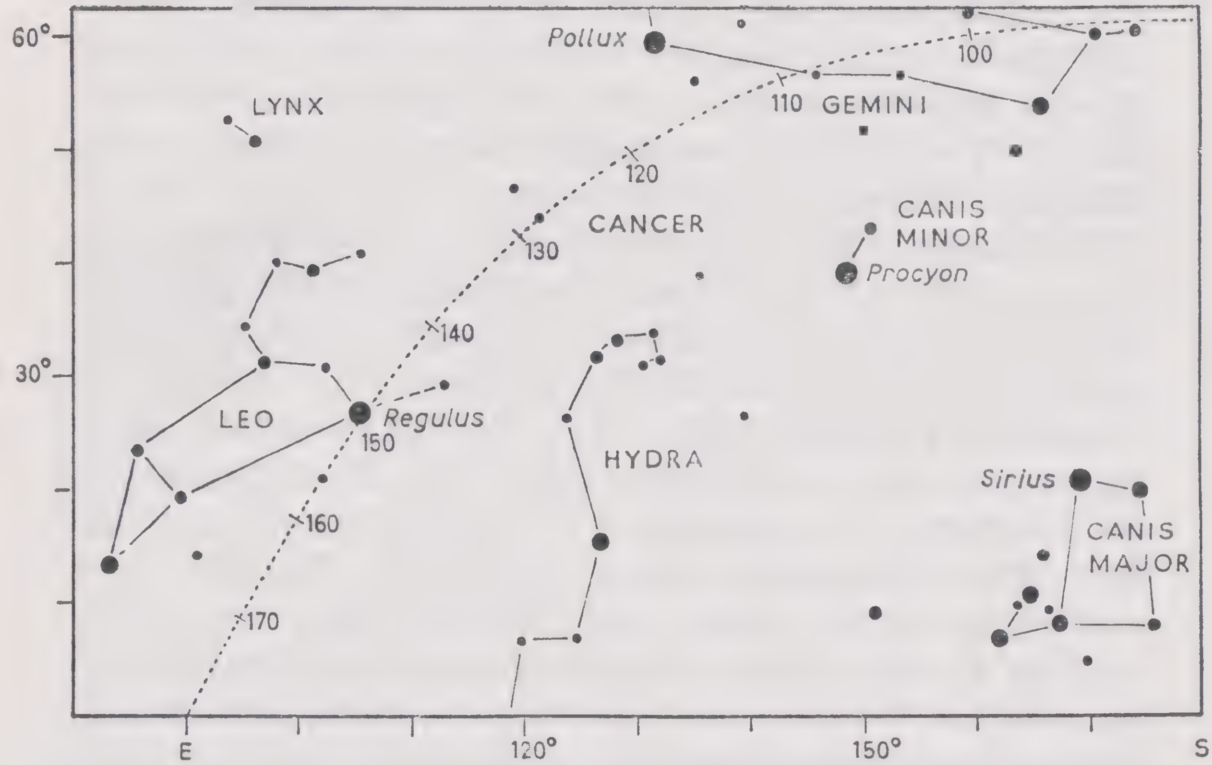
There is a curious illusion that stars at an altitude of 60 degrees or more are actually overhead, and the beginner may often feel that he is leaning over backwards in trying to see them. These high-altitude stars, being nearer the pole, move more slowly across the sky, and a different kind of map may therefore be used. These overhead stars are given separately on pages 44 and 45, the entire year being covered at one opening. Each of the four maps shows the overhead stars at times which correspond to those of three of the main star charts. The position of the zenith in latitude 52 degrees is indicated by a cross, and this cross also marks the centre of a circle which is 35 degrees from the zenith, and which therefore indicates an altitude of 55 degrees; there is thus a small overlap with the main charts.

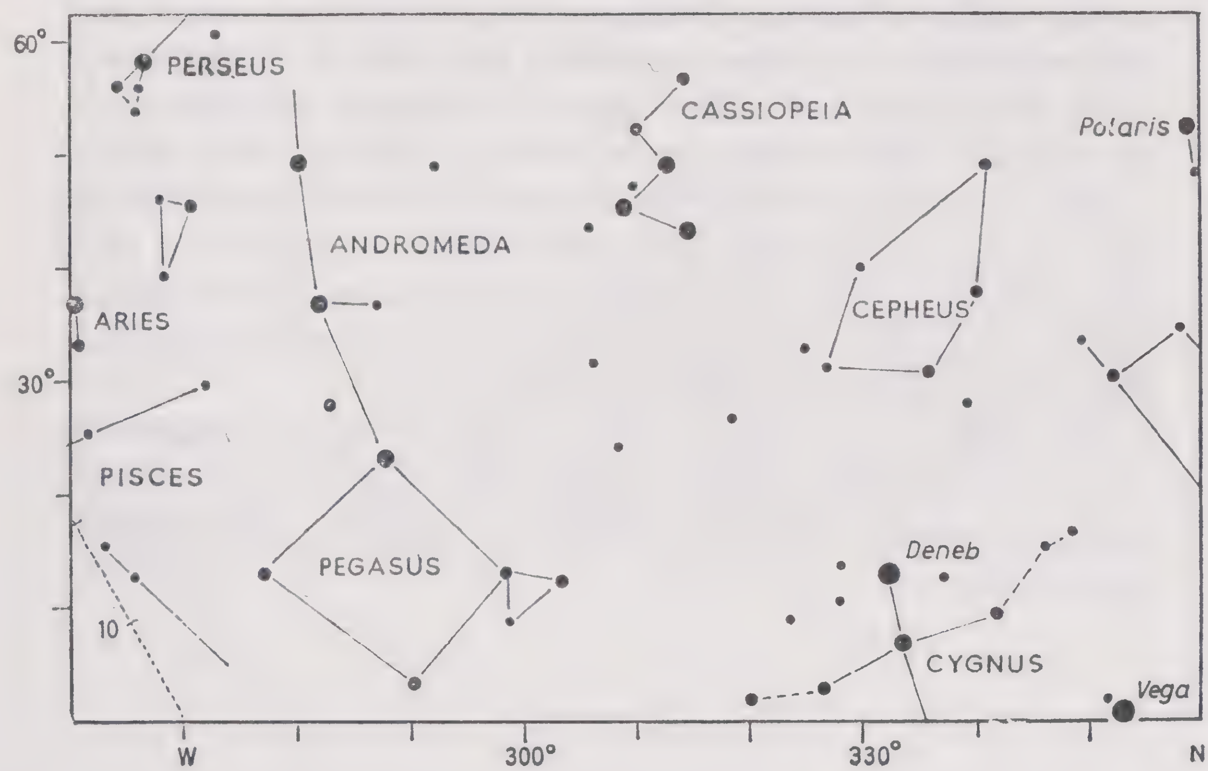
The broken line leading from north to south is numbered to indicate the corresponding main chart. Thus on page 44 the N–S line numbered 6 is to be regarded as an extension of the S line of chart 6 on pages 30 and 31, and at the top of these pages are given dates and times which are appropriate.

The scale is the same on all the charts (approximately 25 degrees to the inch), but the overhead stars are plotted as a true map on a conical projection, and are not simple graphs like the main charts.

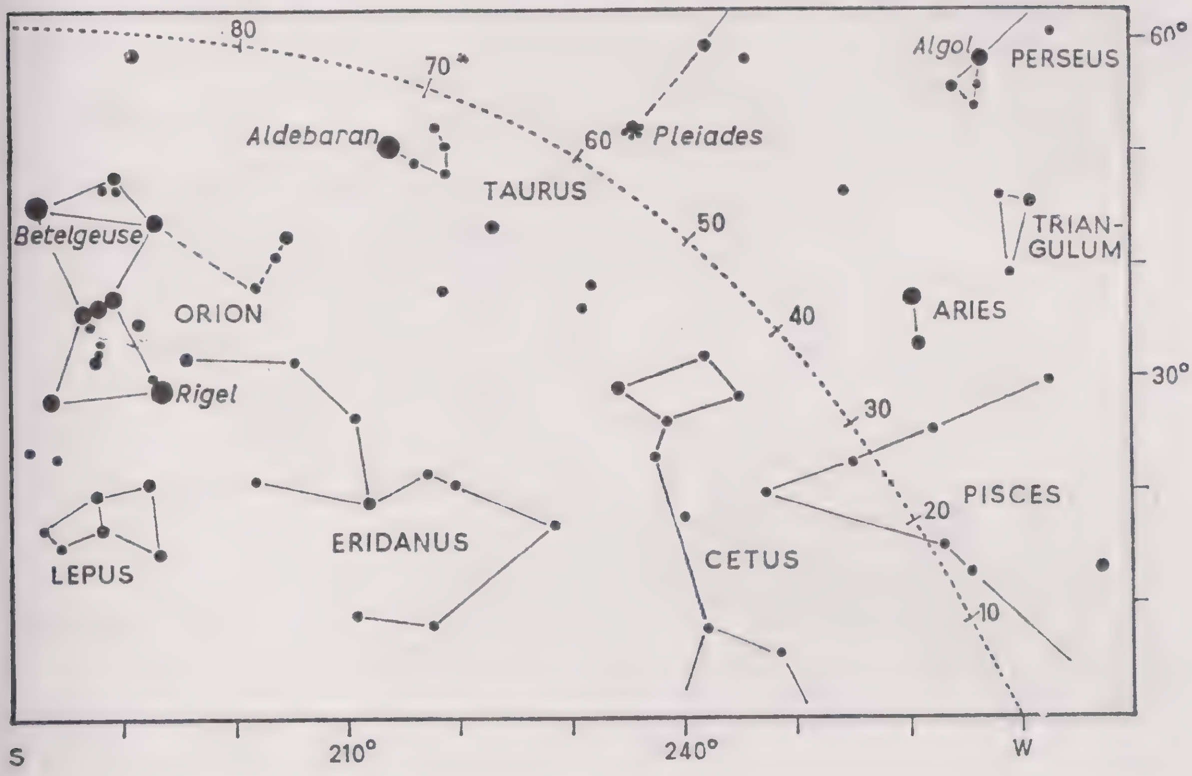
1L

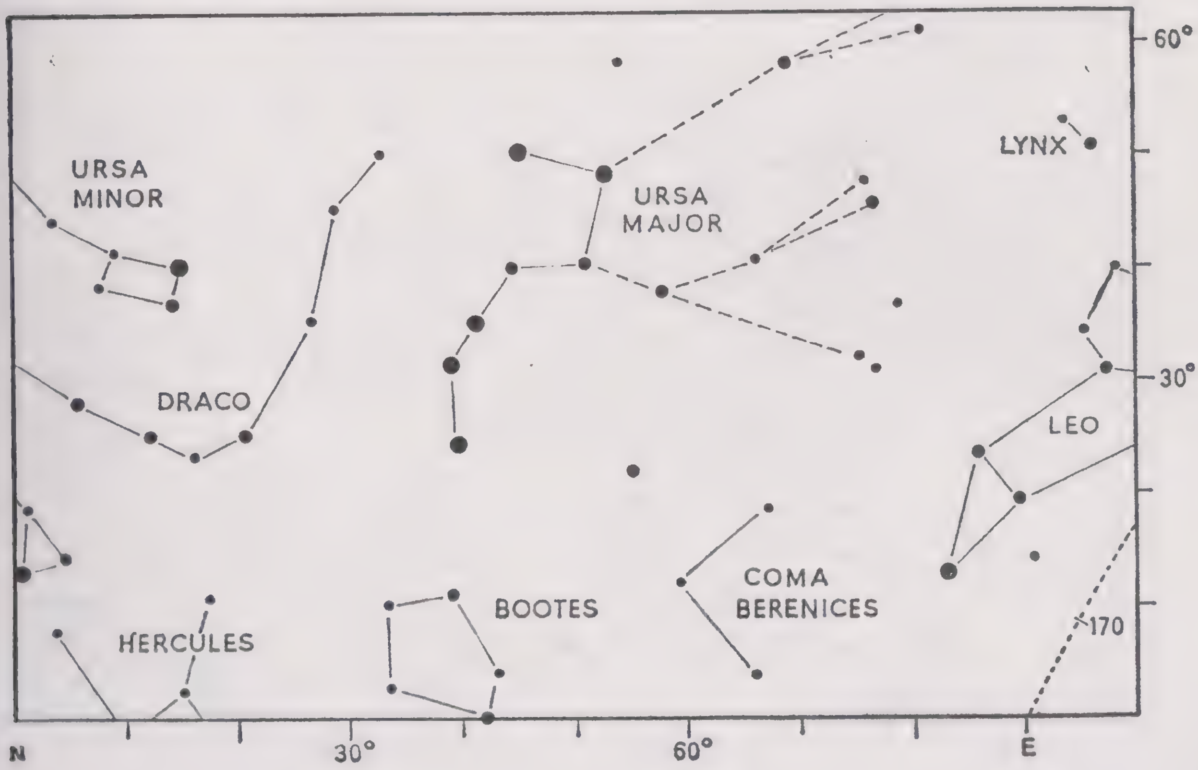
October	6	at	5^h	October	21	at	4^h
November	6	at	3^h	November	21	at	2^h
December	6	at	1^h	December	21	at	midnight
January	6	at	23^h	January	21	at	22^h
February	6	at	21^h	February	21	at	20^h





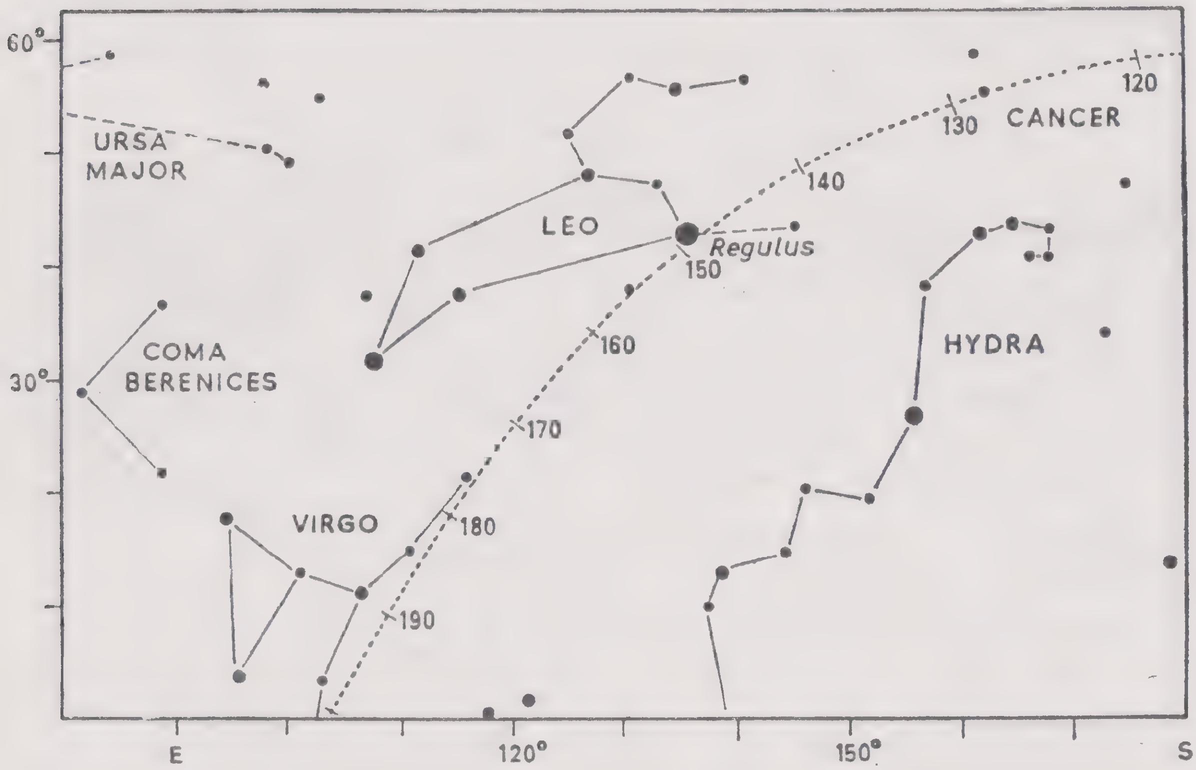
October 6 at 5^h	October 21 at 4^h	
November 6 at 3^h	November 21 at 2^h	
December 6 at 1^h	December 21 at midnight	**1R**
January 6 at 23^h	January 21 at 22^h	
February 6 at 21^h	February 21 at 20^h	

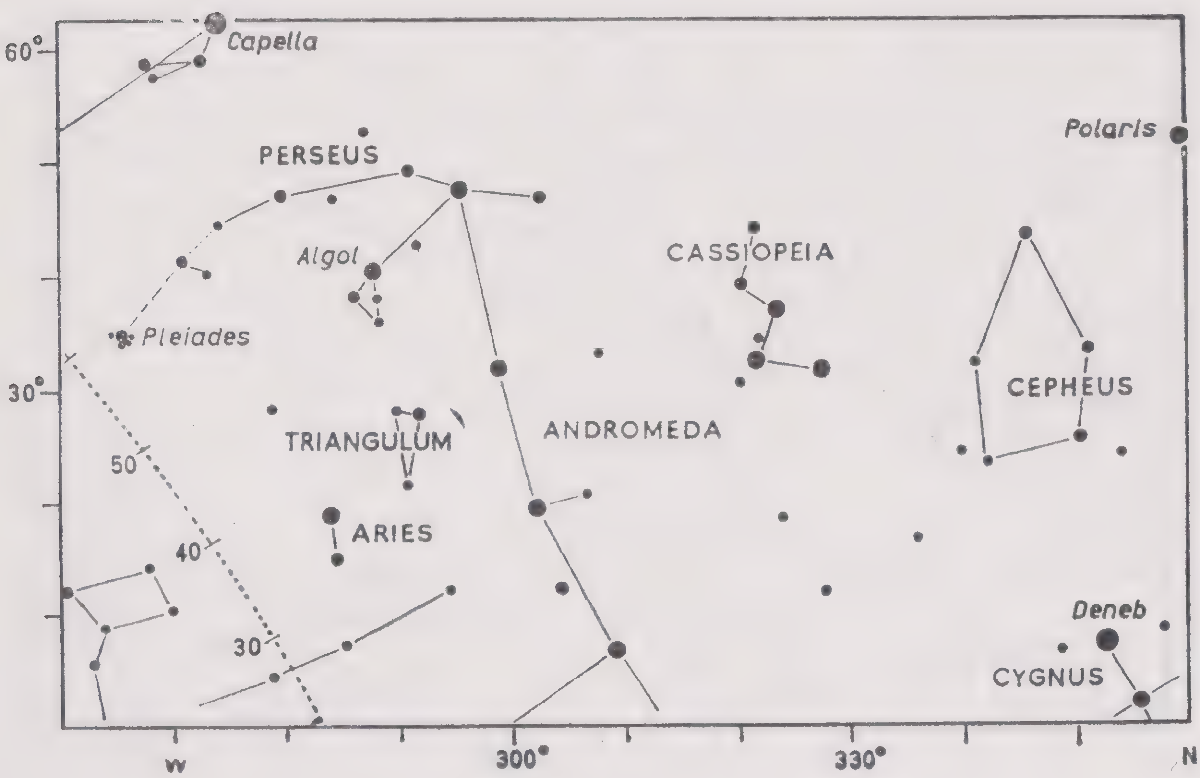




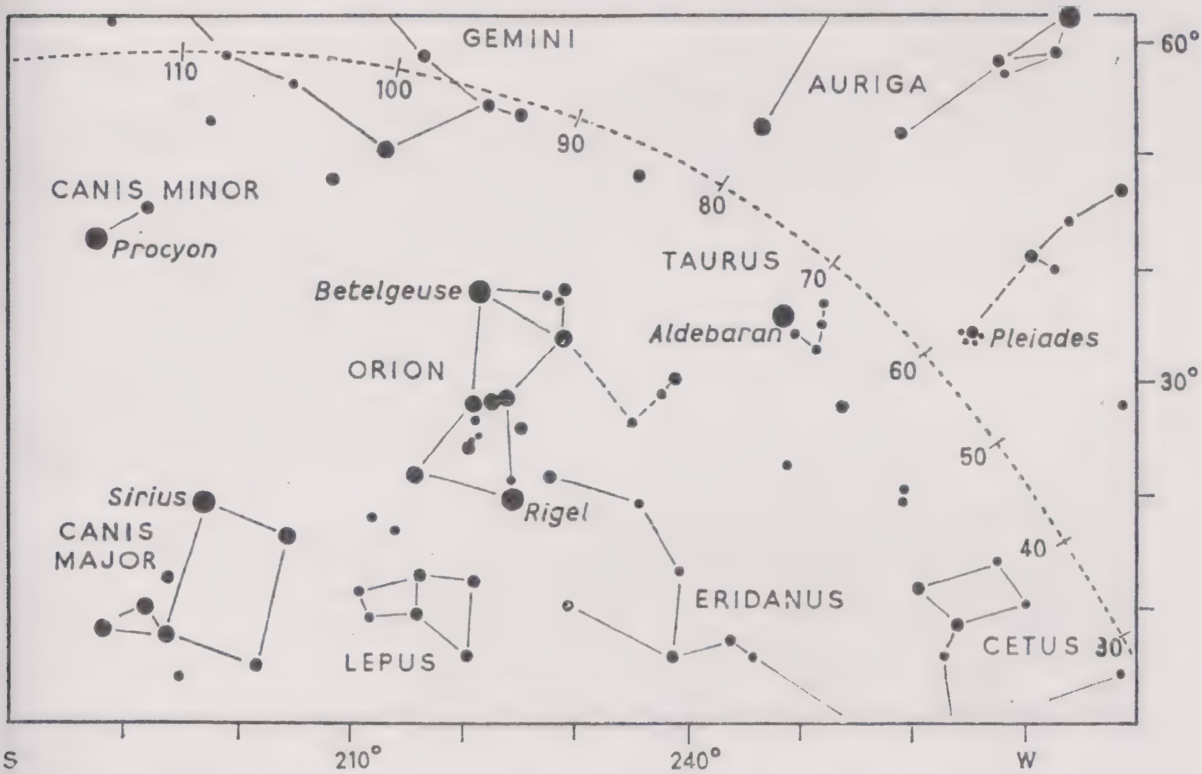
2L

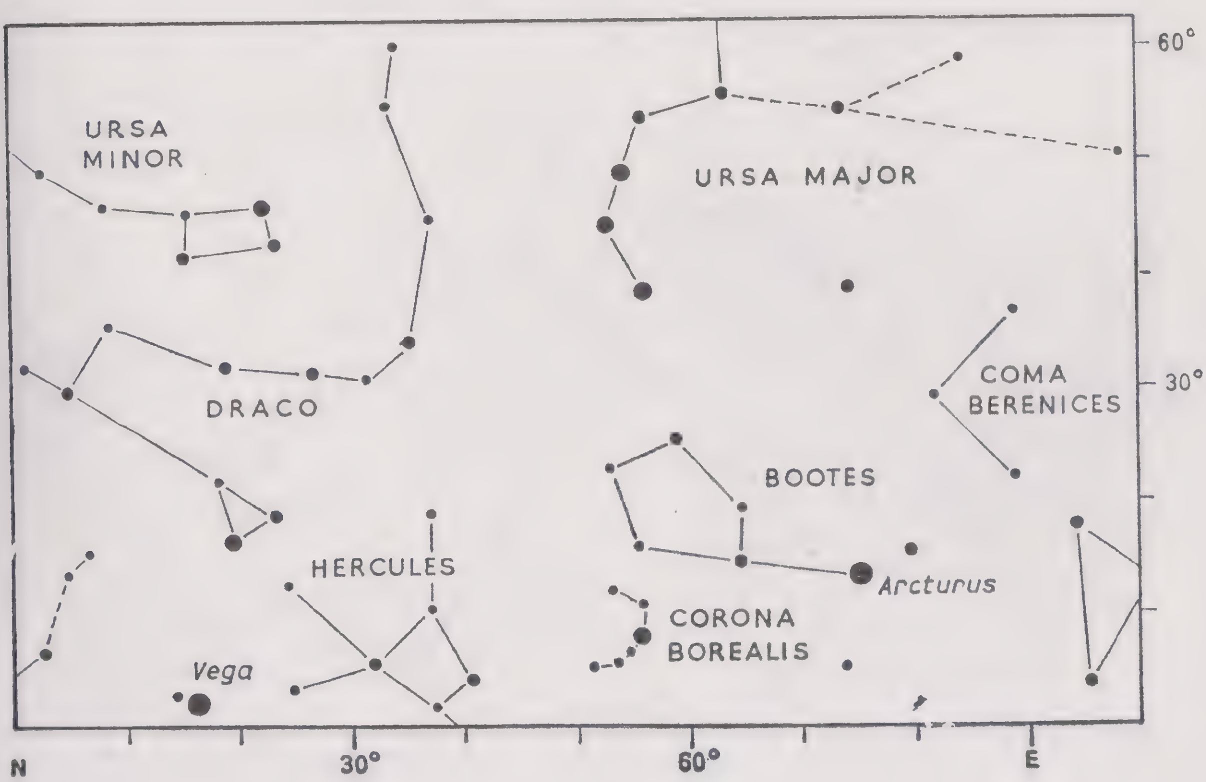
November 6 at	5h	November 21 at	4h
December 6 at	3h	December 21 at	2h
January 6 at	1h	January 21 at	midnight
February 6 at	23h	February 21 at	22h
March 6 at	21h	March 21 at	20h





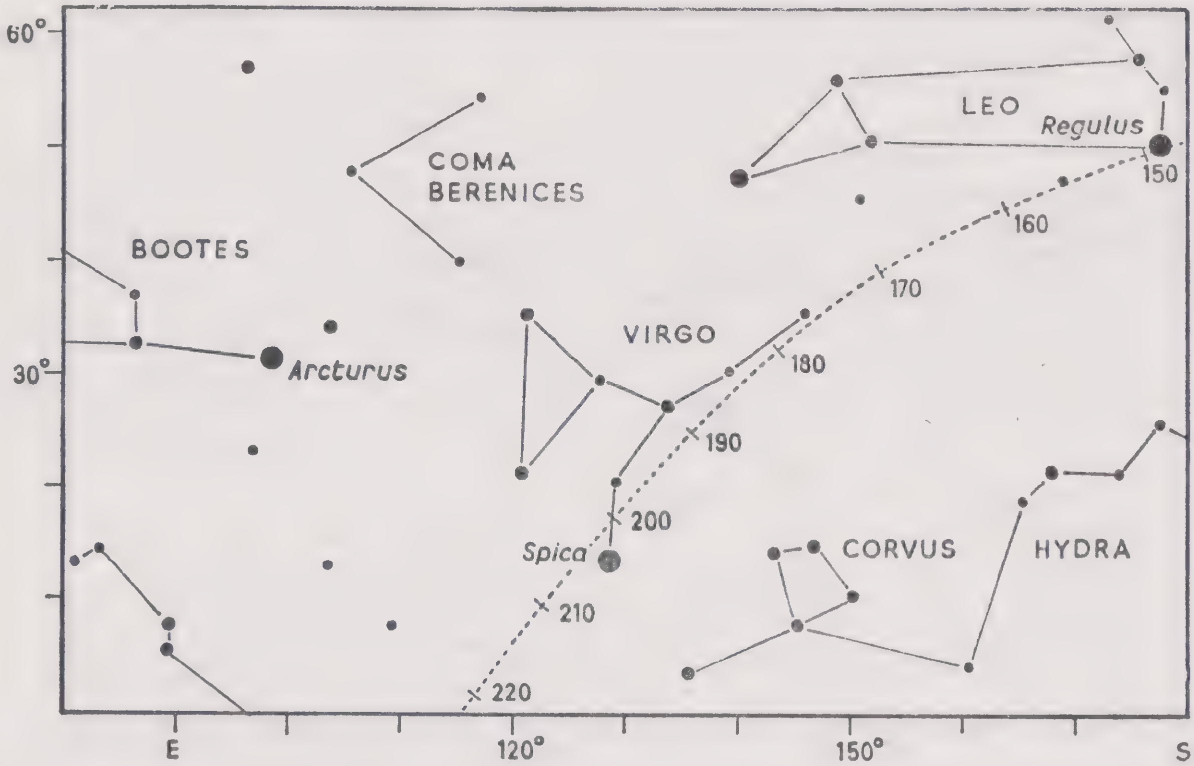
November 6 at 5^h	November 21 at 4^h	**2R**
December 6 at 3^h	December 21 at 2^h	
January 6 at 1^h	January 21 at midnight	
February 6 at 23^h	February 21 at 22^h	
March 6 at 21^h	March 21 at 20^h	

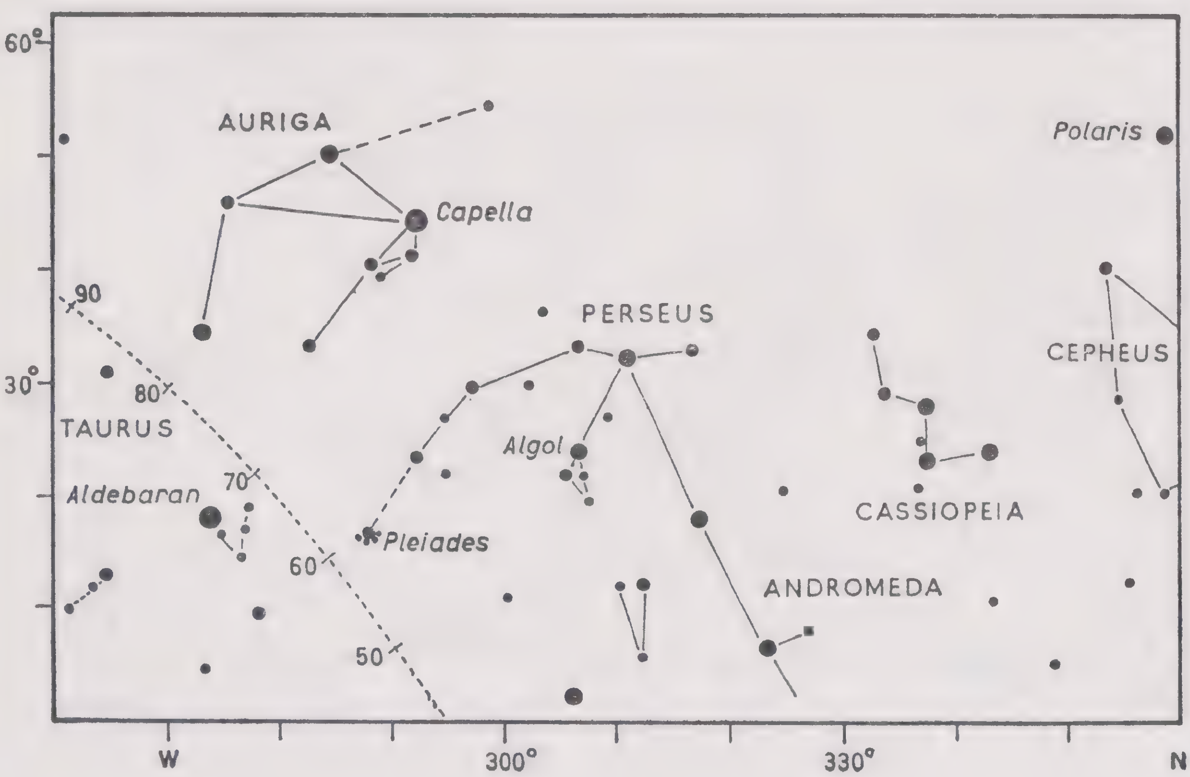




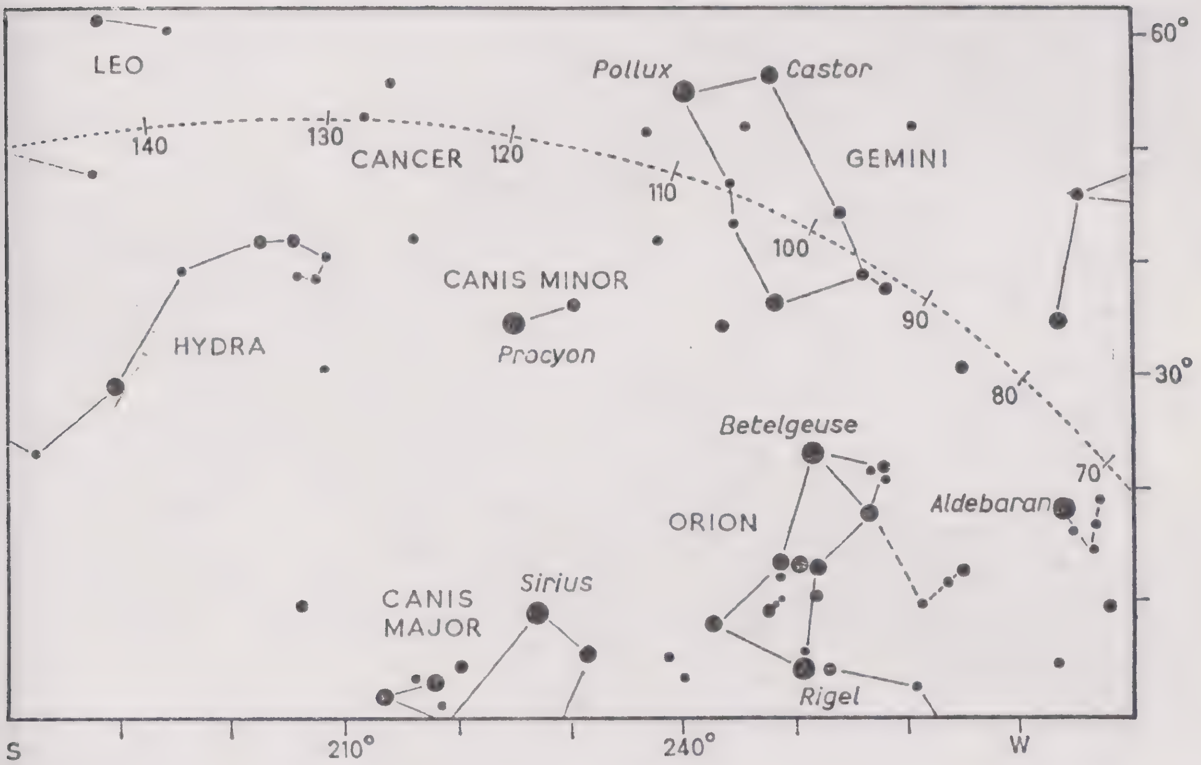
3L

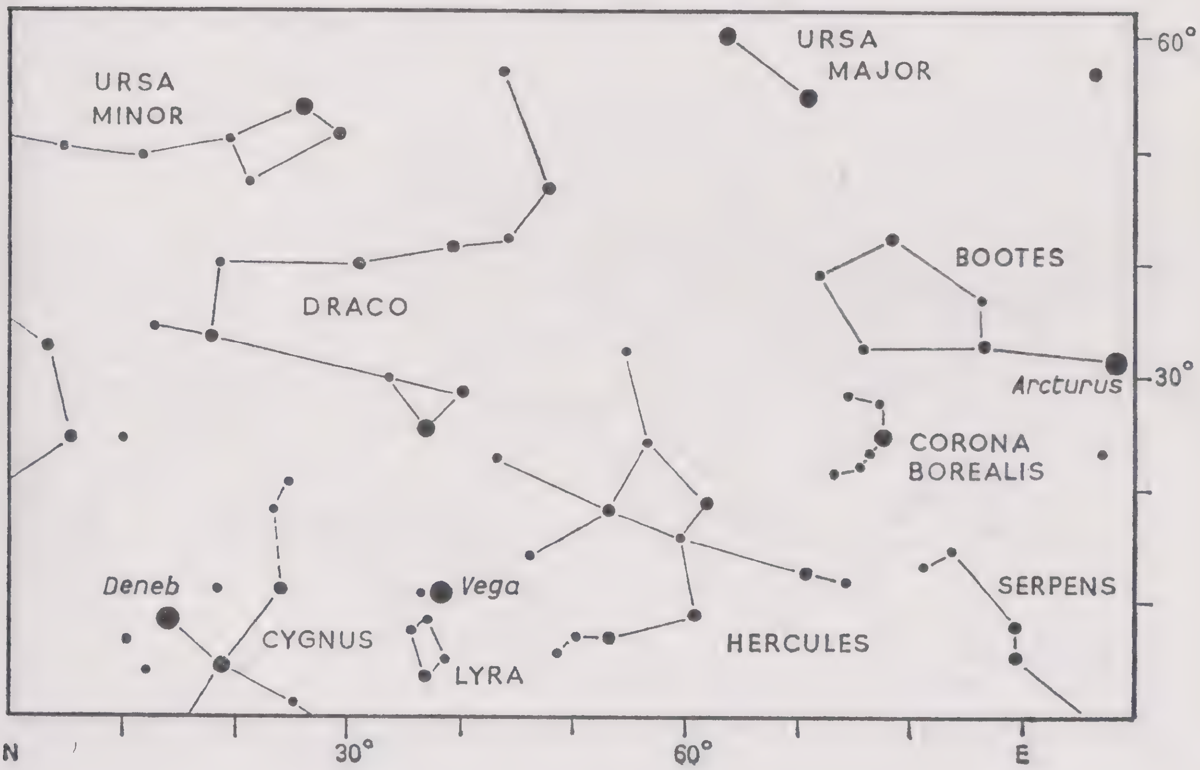
December 6 at 5^h	December 21 at 4^h
January 6 at 3^h	January 21 at 2^h
February 6 at 1^h	February 21 at midnight
March 6 at 23^h	March 21 at 22^h
April 6 at 21^h	April 21 at 20^h





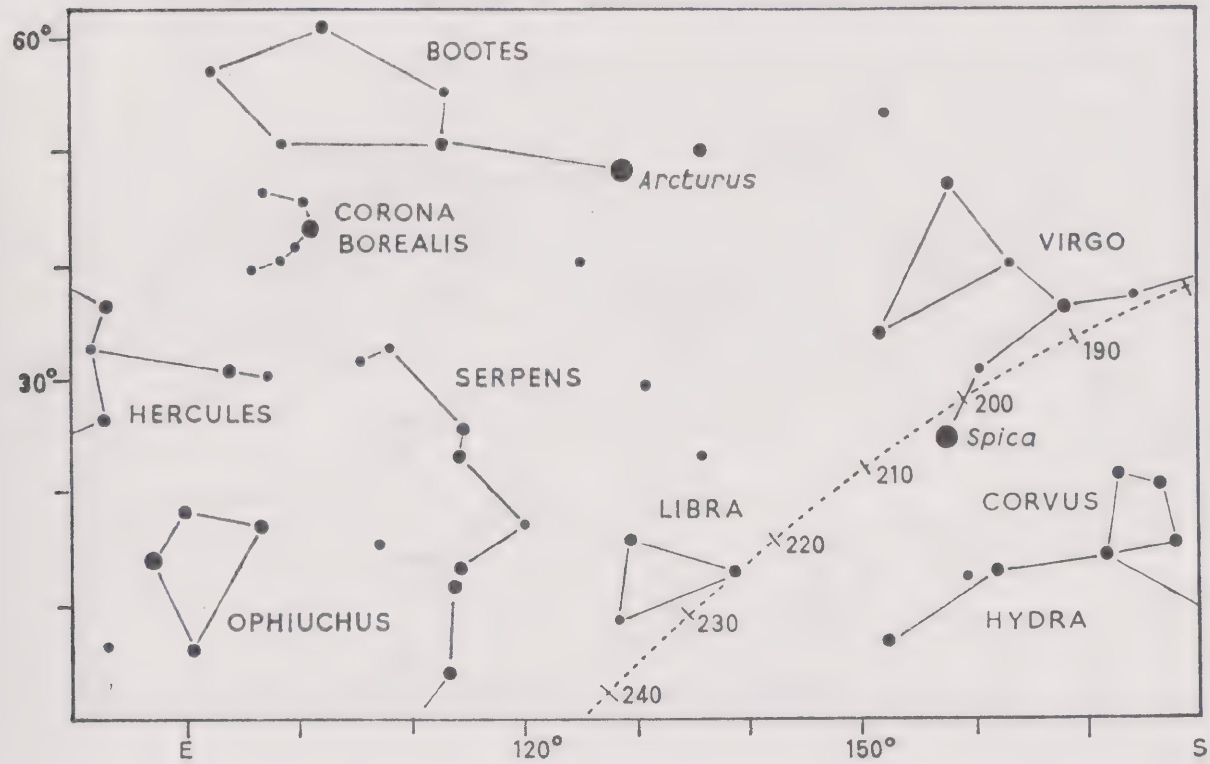
December 6 at 5^h	December 21 at 4^h		
January 6 at 3^h	January 21 at 2^h		
February 6 at 1^h	February 21 at midnight		**3R**
March 6 at 23^h	March 21 at 22^h		
April 6 at 21^h	April 21 at 20^h		

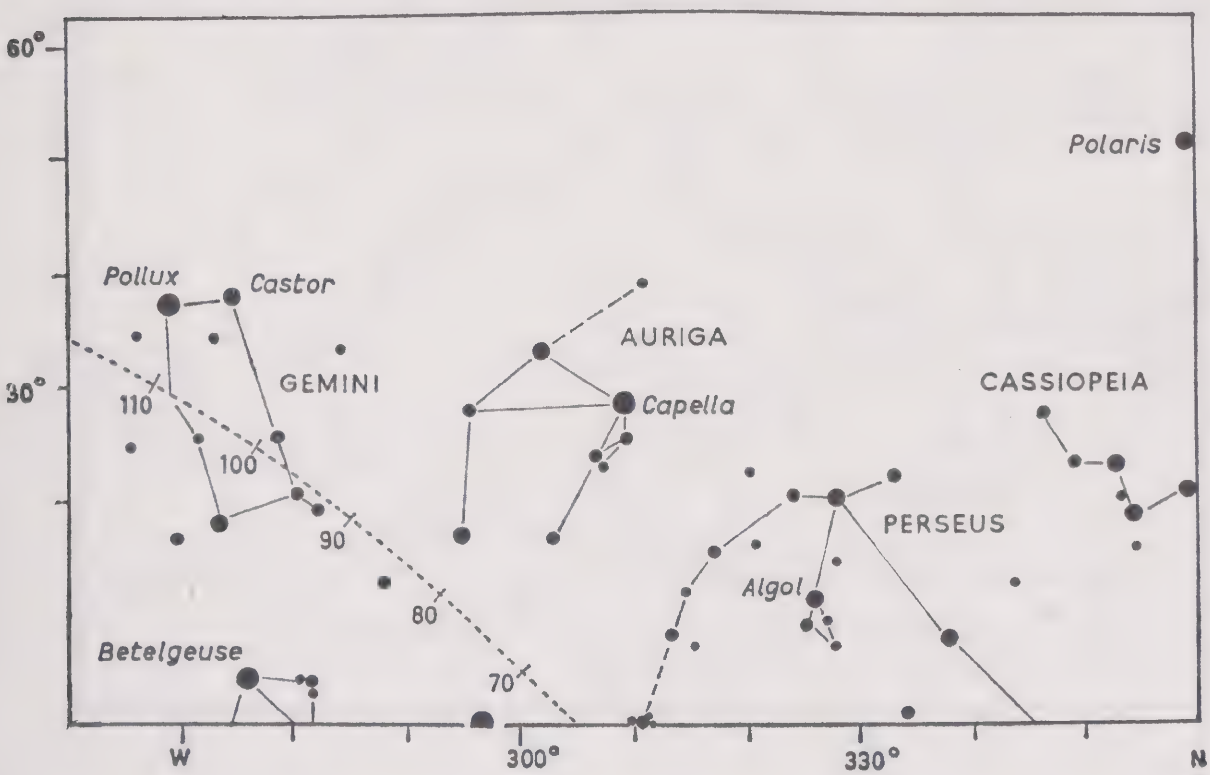




4L

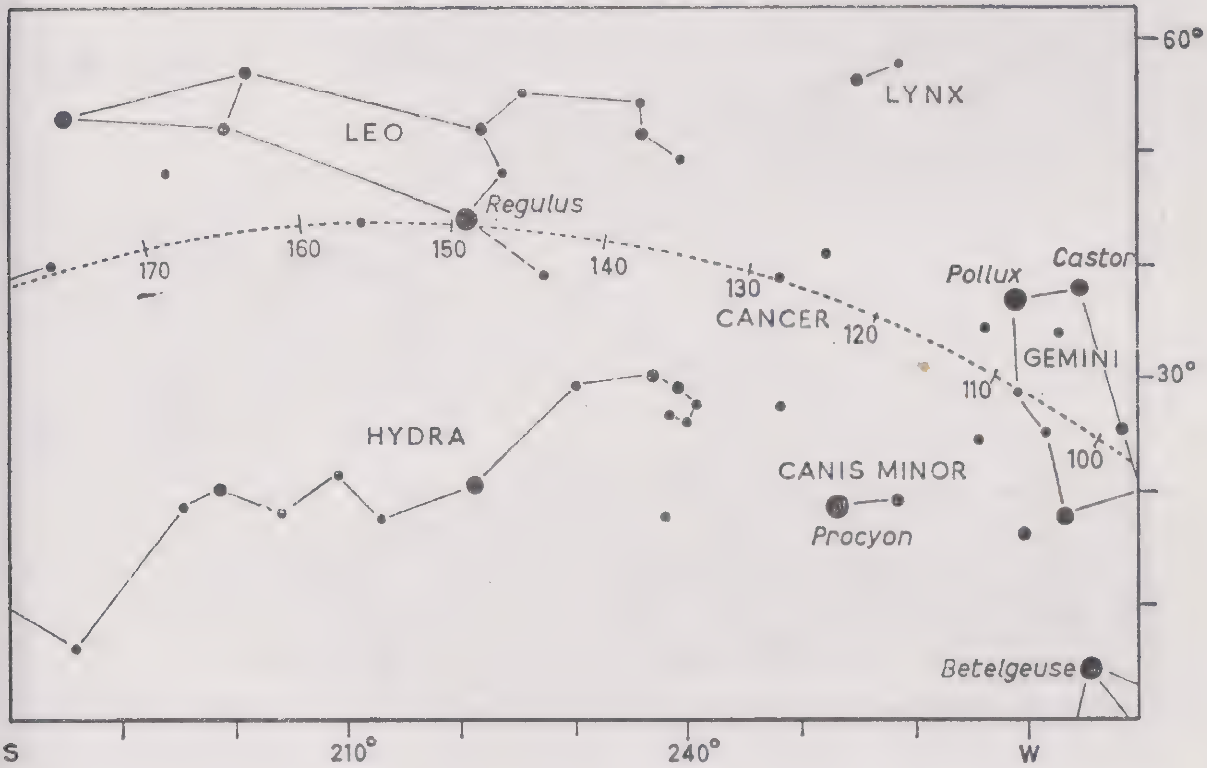
January 6 at	5^h	January 21 at	4^h
February 6 at	3^h	February 21 at	2^h
March 6 at	1^h	March 21 at	midnight
April 6 at	23^h	April 21 at	22^h
May 6 at	21^h	May 21 at	20^h

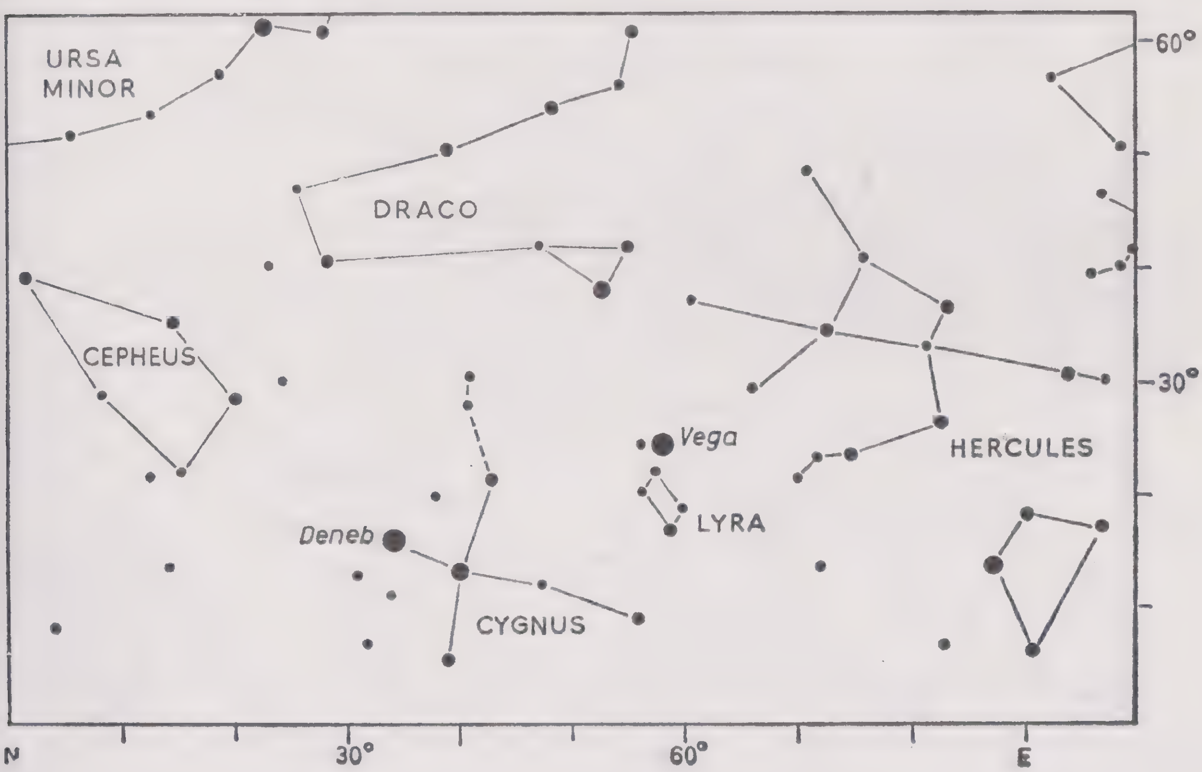




January 6 at	5^h	January 21 at	4^h
February 6 at	3^h	February 21 at	2^h
March 6 at	1^h	March 21 at	midnight
April 6 at	23^h	April 21 at	22^h
May 6 at	21^h	May 21 at	20^h

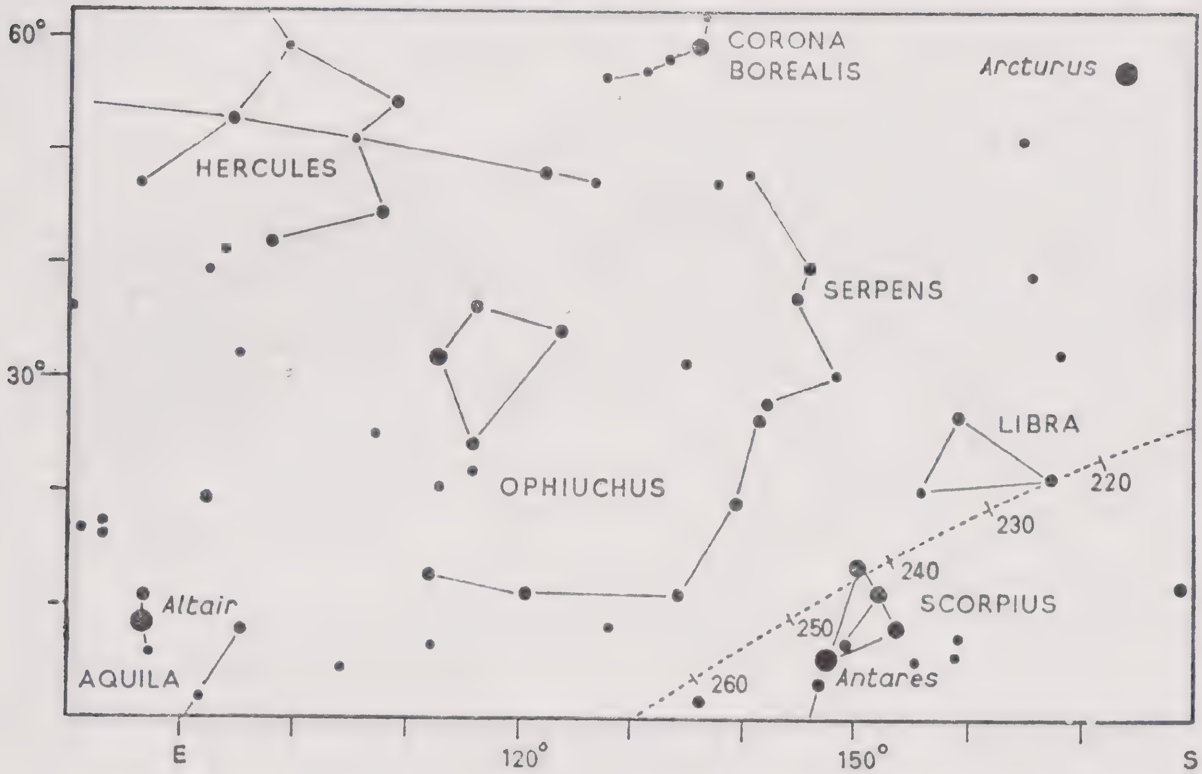
4R

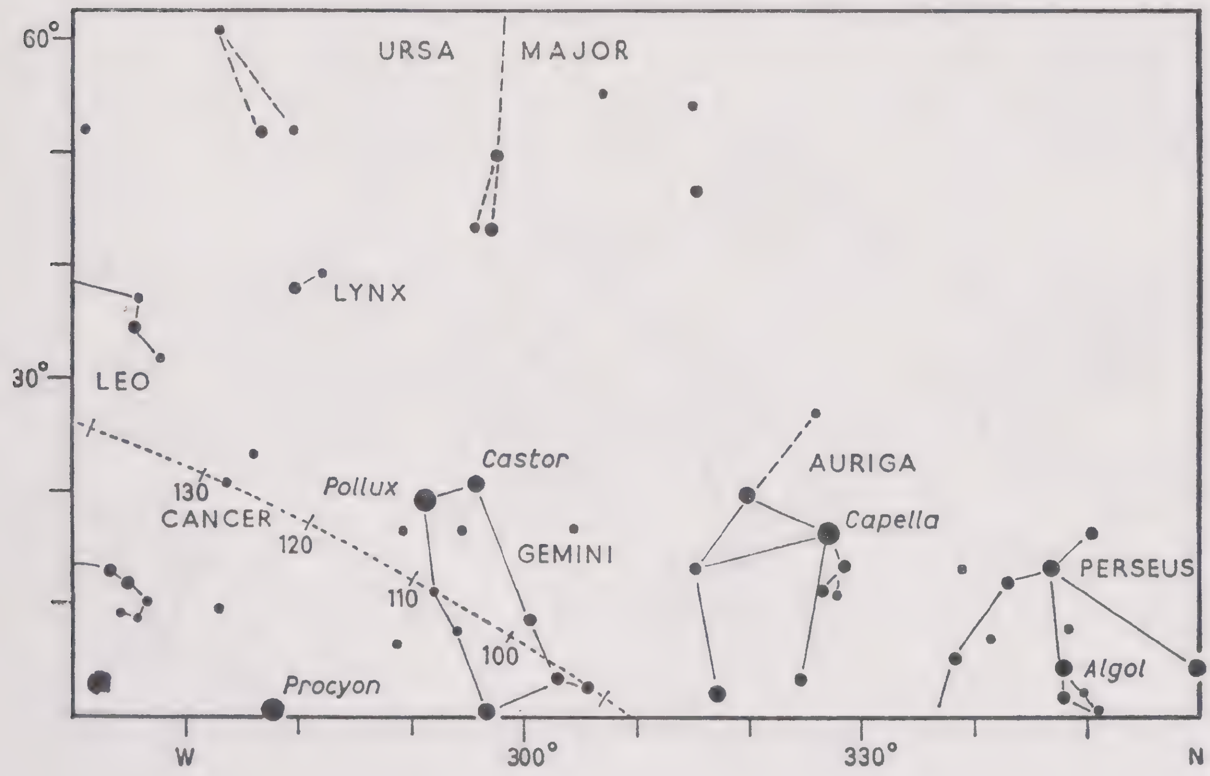




5L

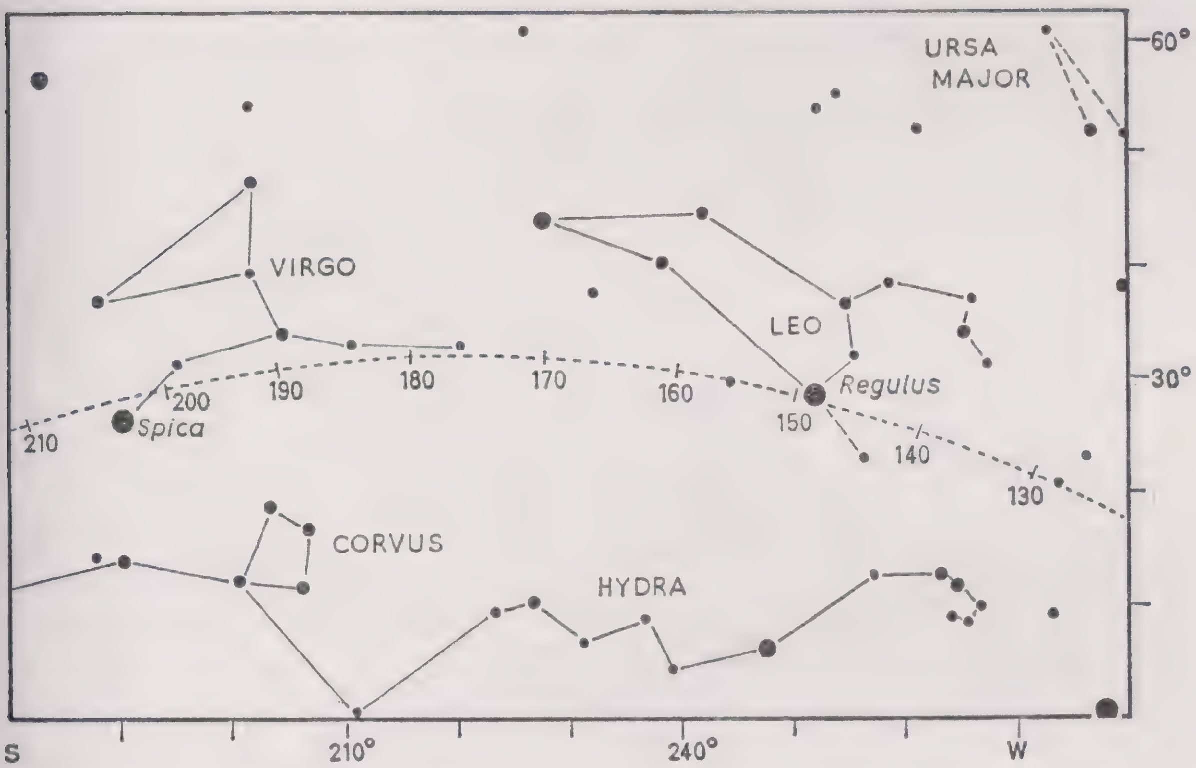
January 6 at 7^{h}	January 21 at 6^{h}
February 6 at 5^{h}	February 21 at 4^{h}
March 6 at 3^{h}	March 21 at 2^{h}
April 6 at 1^{h}	April 21 at midnight
May 6 at 23^{h}	May 21 at 22^{h}

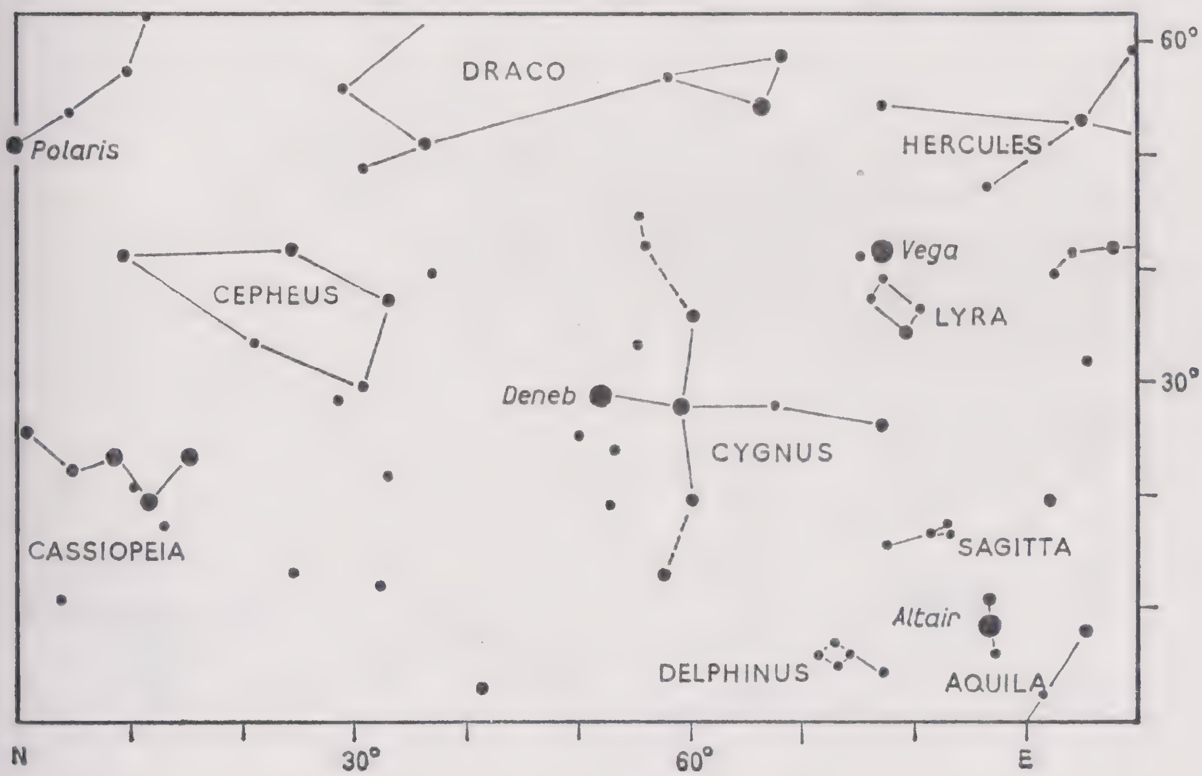




January 6 at 7^h	January 21 at 6^h
February 6 at 5^h	February 21 at 4^h
March 6 at 3^h	March 21 at 2^h
April 6 at 1^h	April 21 at midnight
May 6 at 23^h	May 21 at 22^h

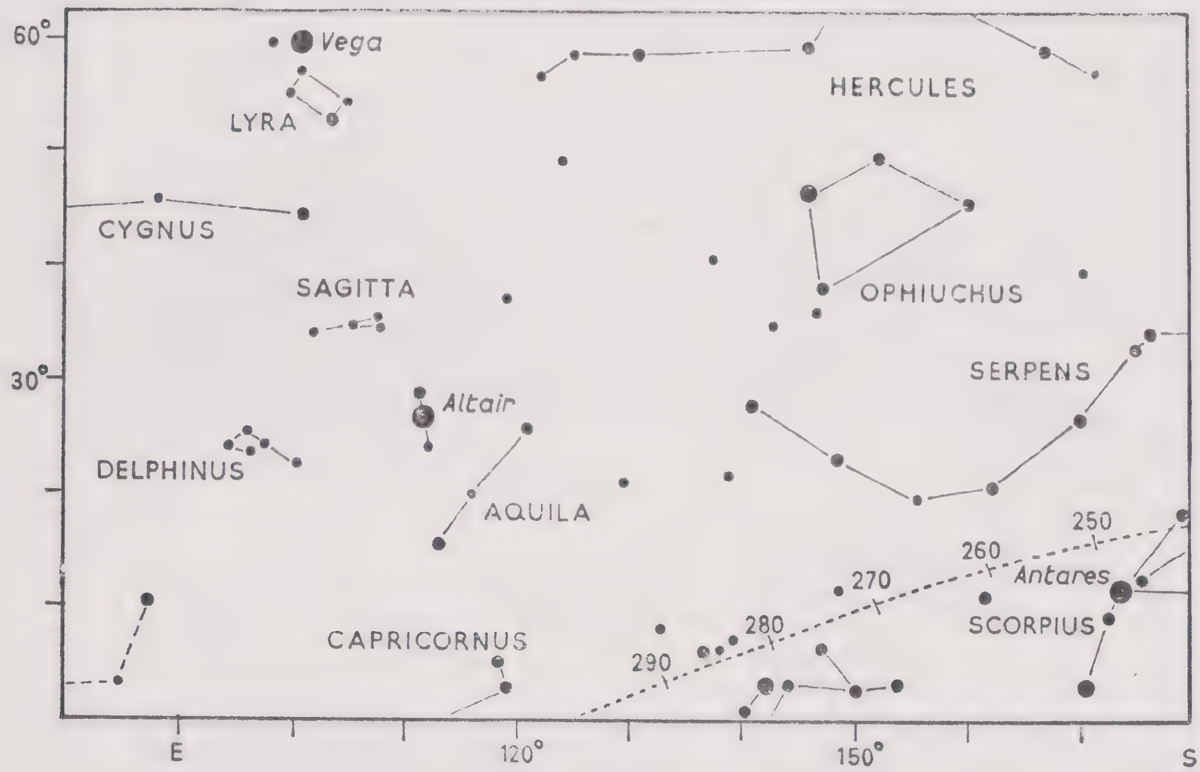
5R

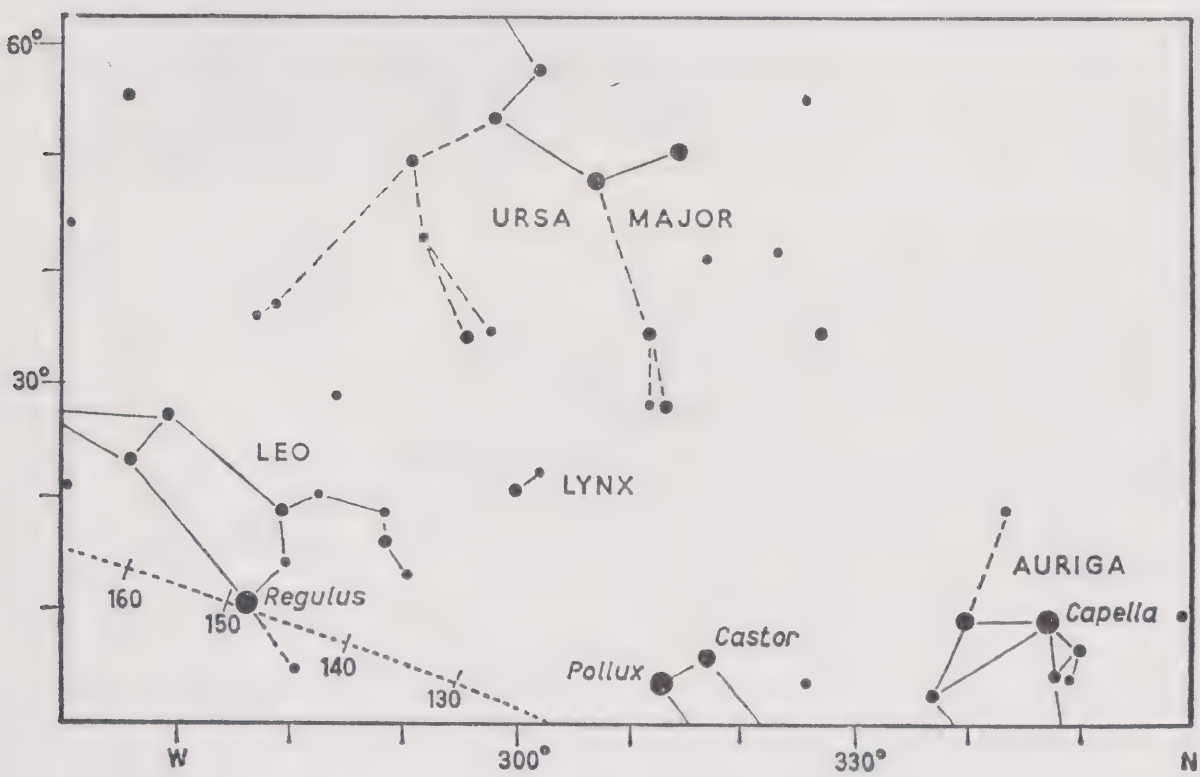




6L

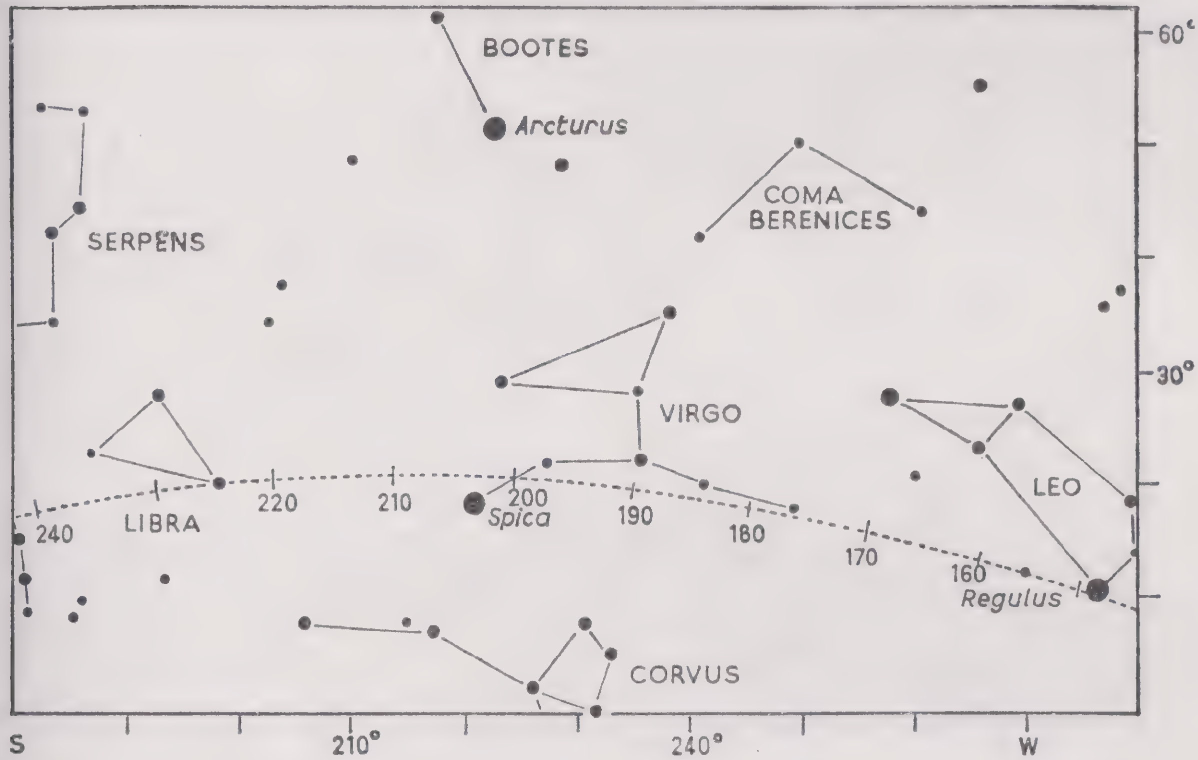
March 6 at 5^h	March 21 at 4^h
April 6 at 3^h	April 21 at 2^h
May 6 at 1^h	May 21 at midnight
June 6 at 23^h	June 21 at 22^h
July 6 at 21^h	July 21 at 20^h

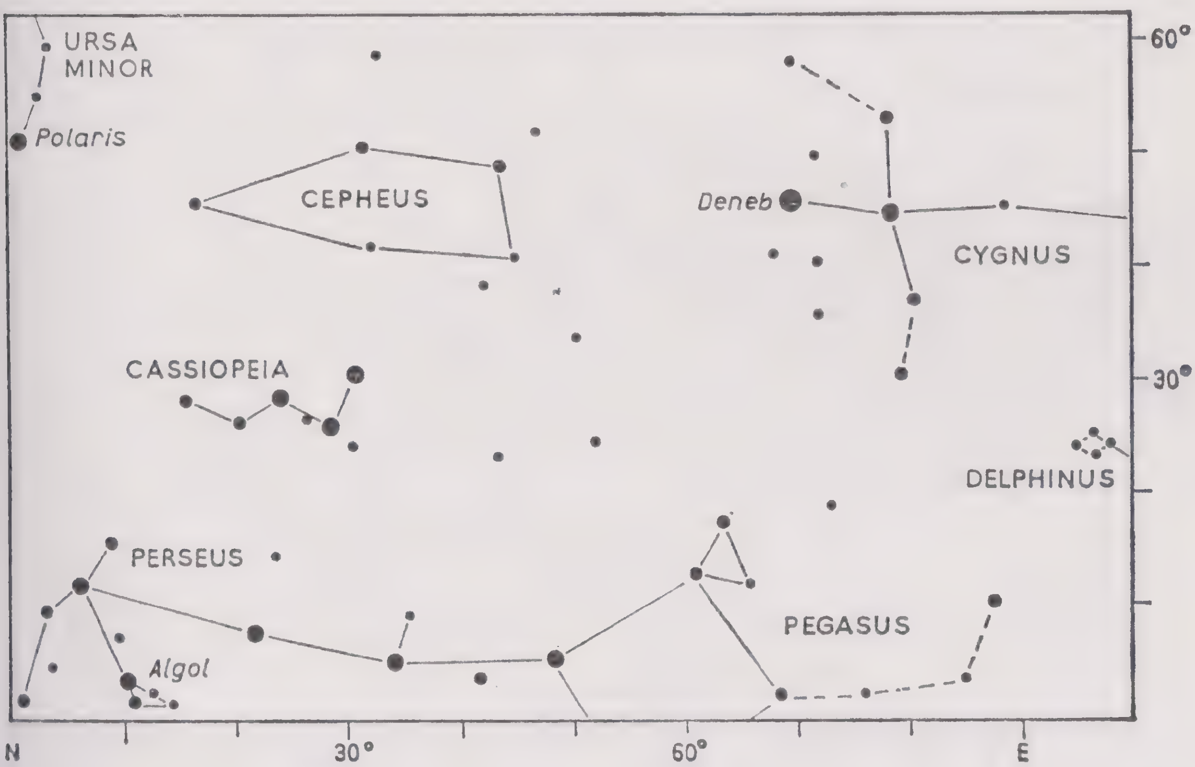




March 6 at 5^h	March 21 at 4^h
April 6 at 3^h	April 21 at 2^h
May 6 at 1^h	May 21 at midnight
June 6 at 23^h	June 21 at 22^h
July 6 at 21^h	July 21 at 20^h

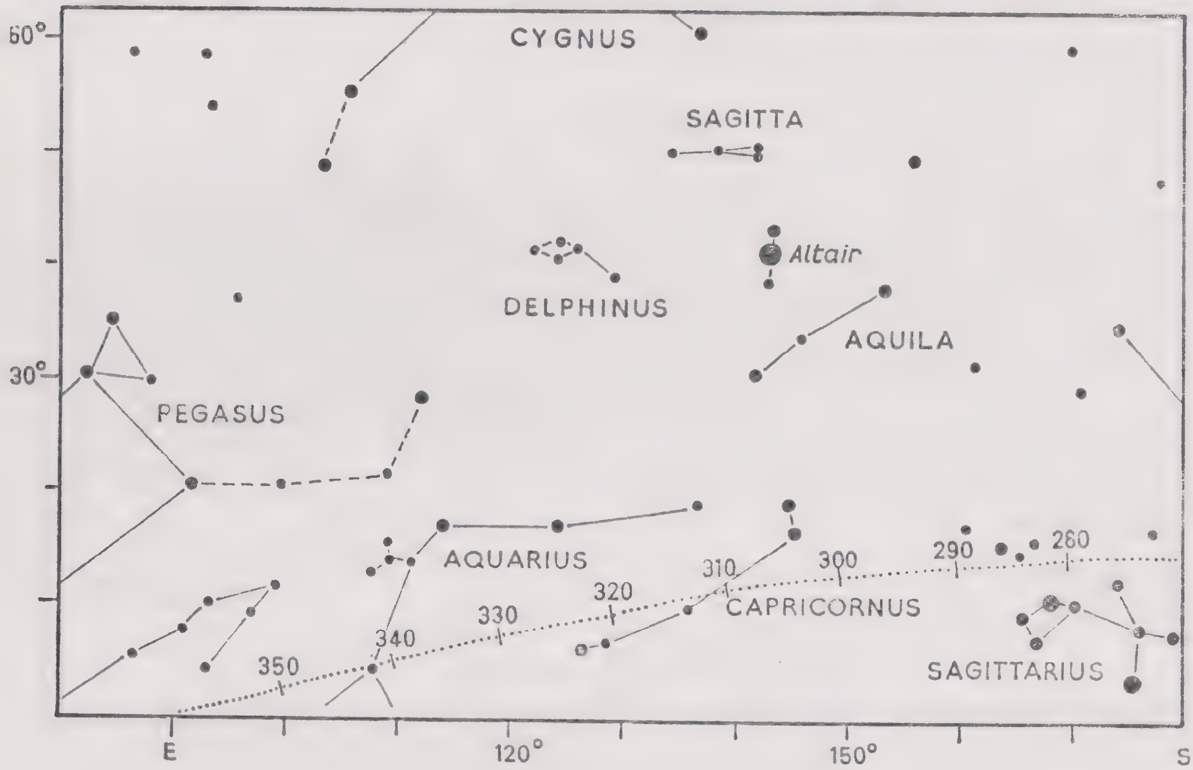
6R

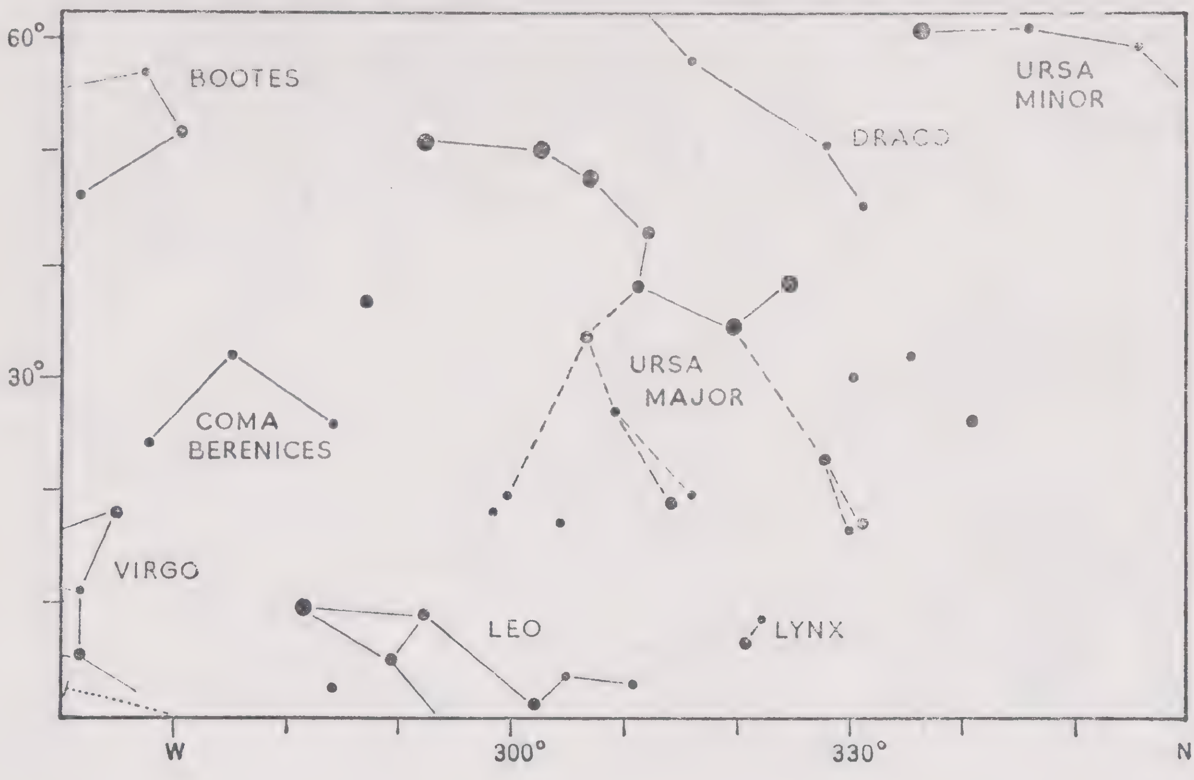




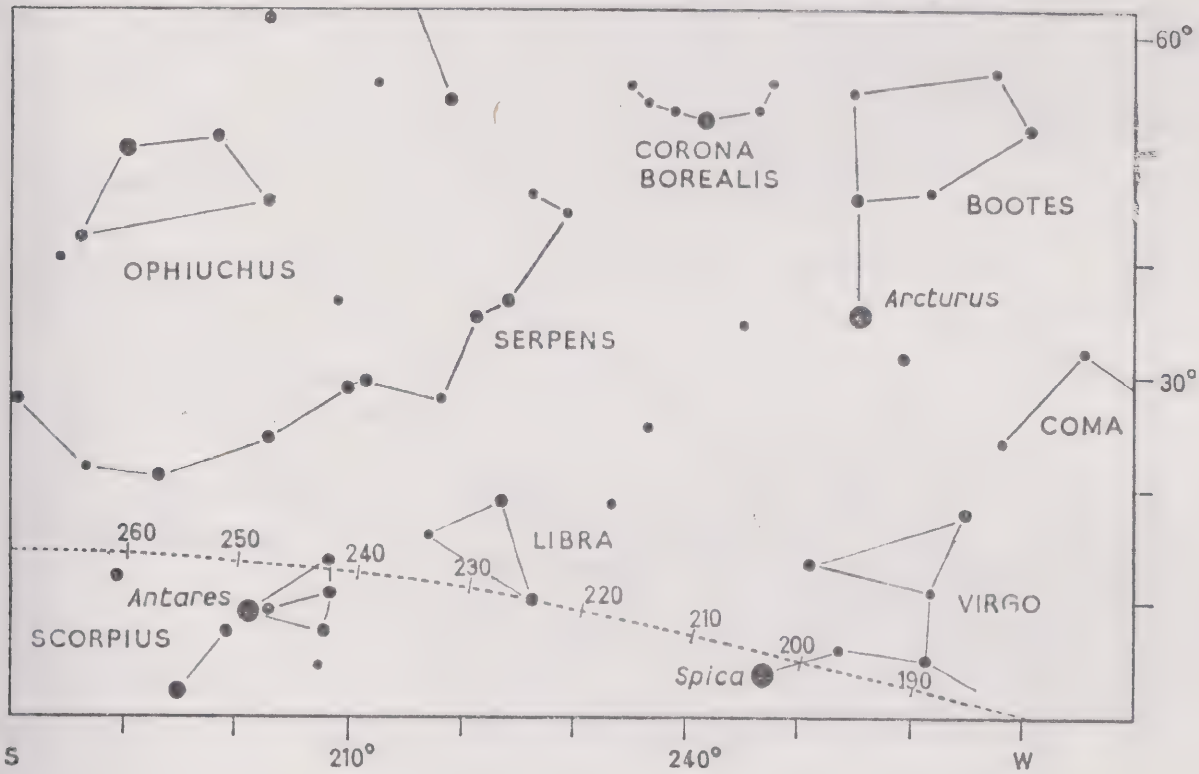
7L

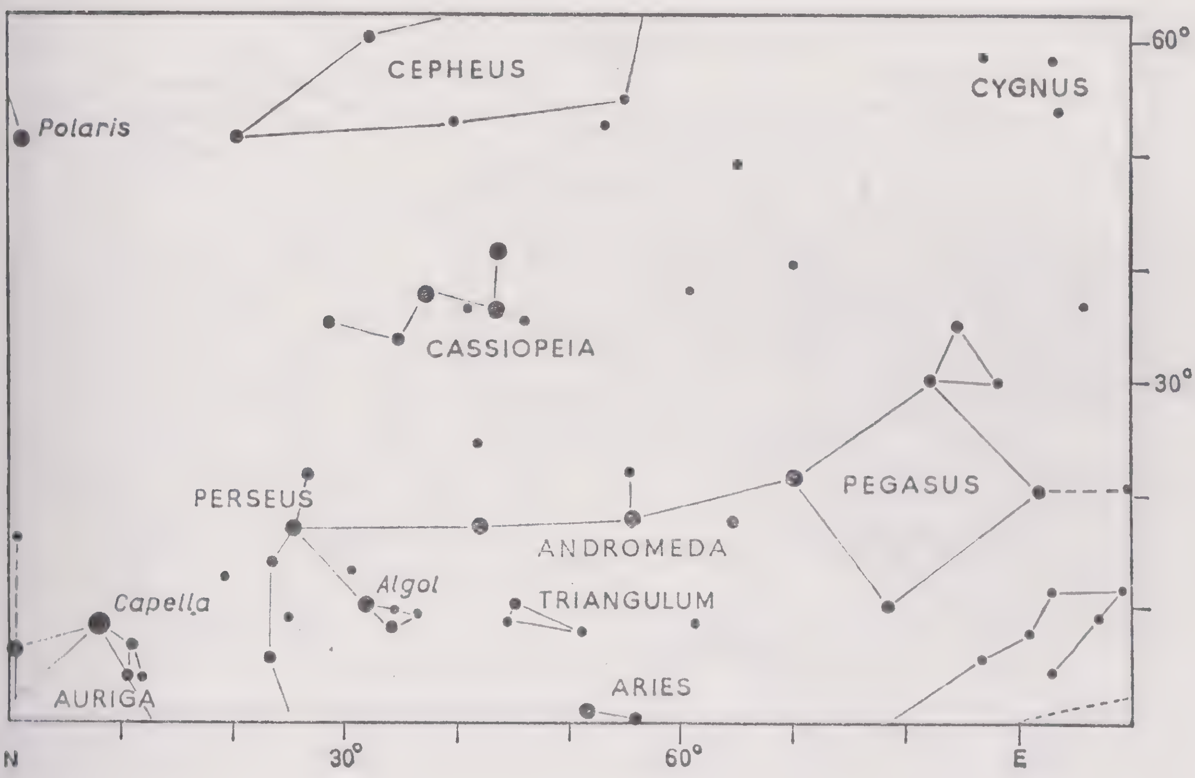
May	6 at	3h		May	21	at	2h
June	6 at	1h		June	21	at	midnight
July	6 at	23h		July	21	at	22h
August	6 at	21h		August	21	at	20h
September	6 at	19h		September	21	at	18h





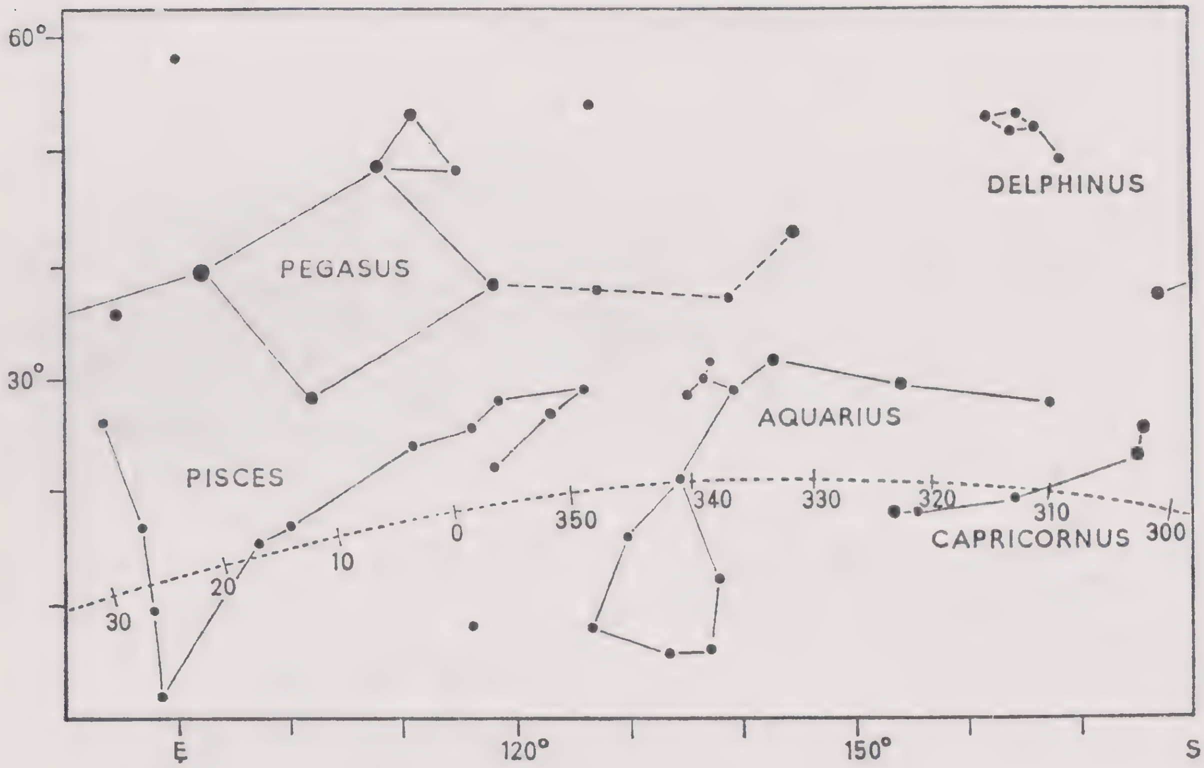
May 6 at 3^h	May 21 at 2^h	
June 6 at 1^h	June 21 at midnight	**7R**
July 6 at 23^h	July 21 at 22^h	
August 6 at 21^h	August 21 at 20^h	
September 6 at 19^h	September 21 at 18^h	

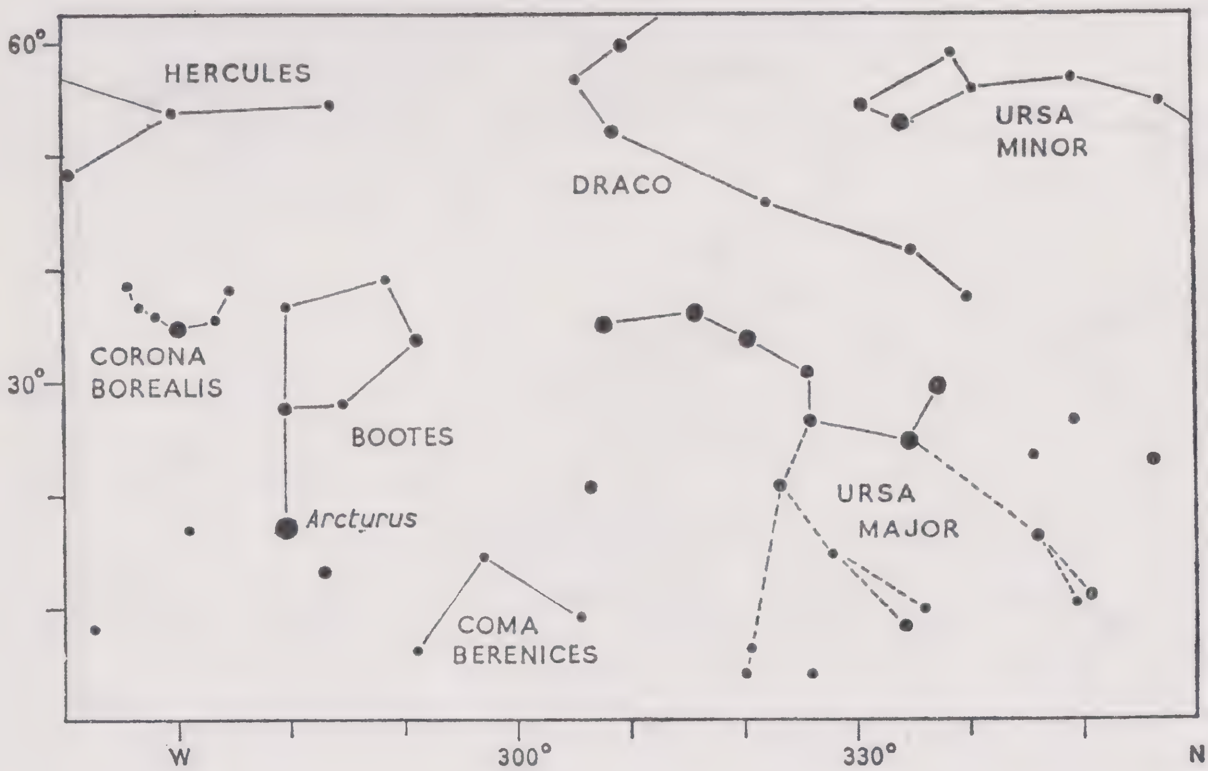




8L

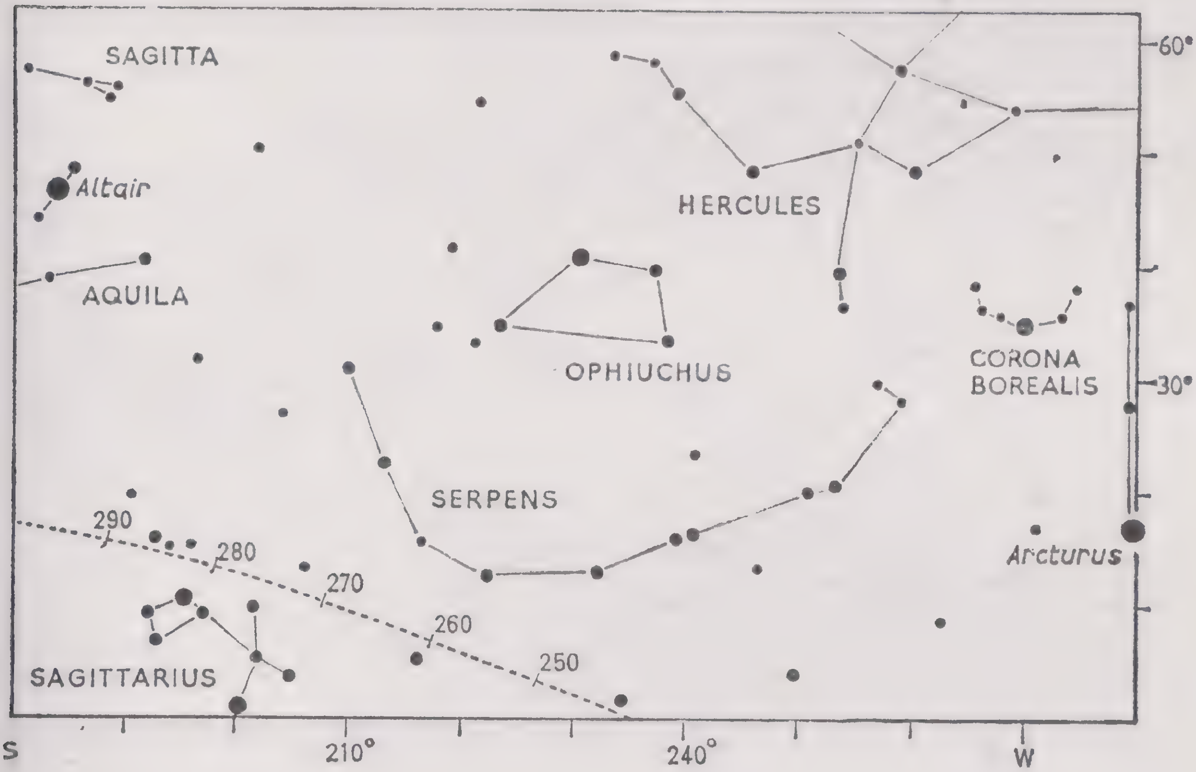
July 6 at 1^h	July 21 at midnight
August 6 at 23^h	August 21 at 22^h
September 6 at 21^h	September 21 at 20^h
October 6 at 19^h	October 21 at 18^h
November 6 at 17^h	November 21 at 16^h

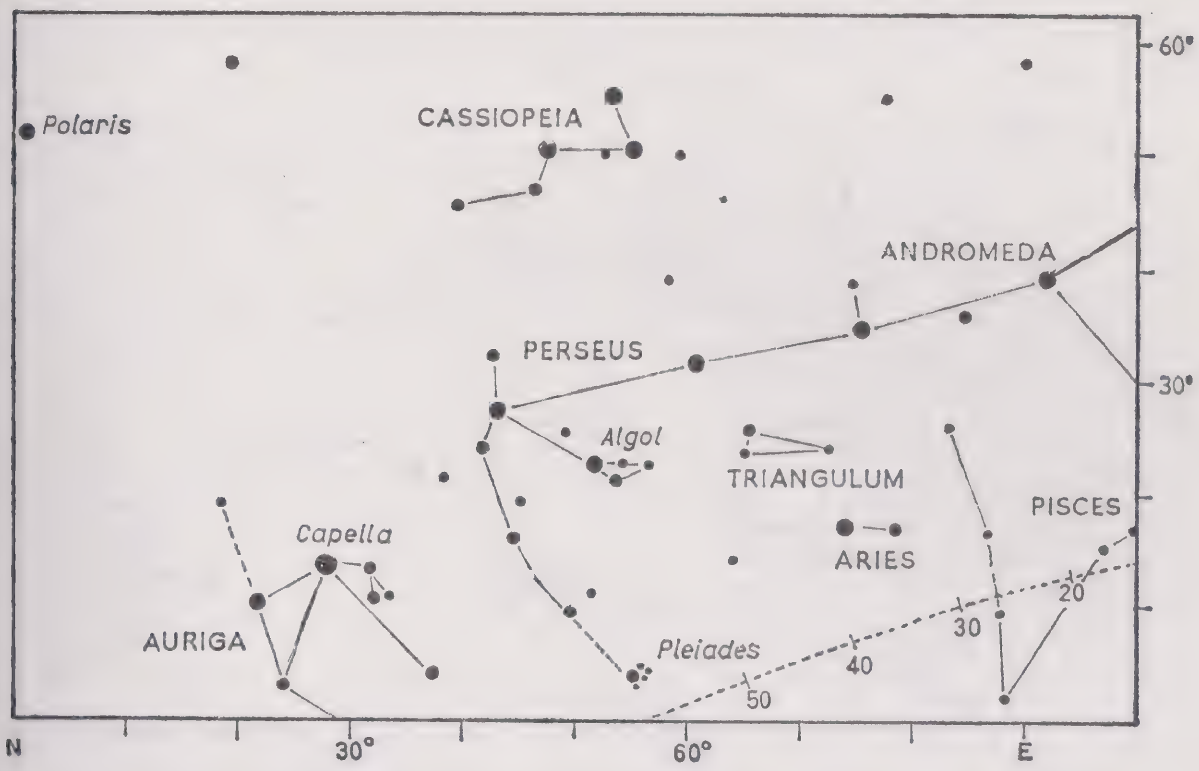




July 6 at 1^h	July 21 at midnight
August 6 at 23^h	August 21 at 22^h
September 6 at 21^h	September 21 at 20^h
October 6 at 19^h	October 21 at 18^h
November 6 at 17^h	November 21 at 16^h

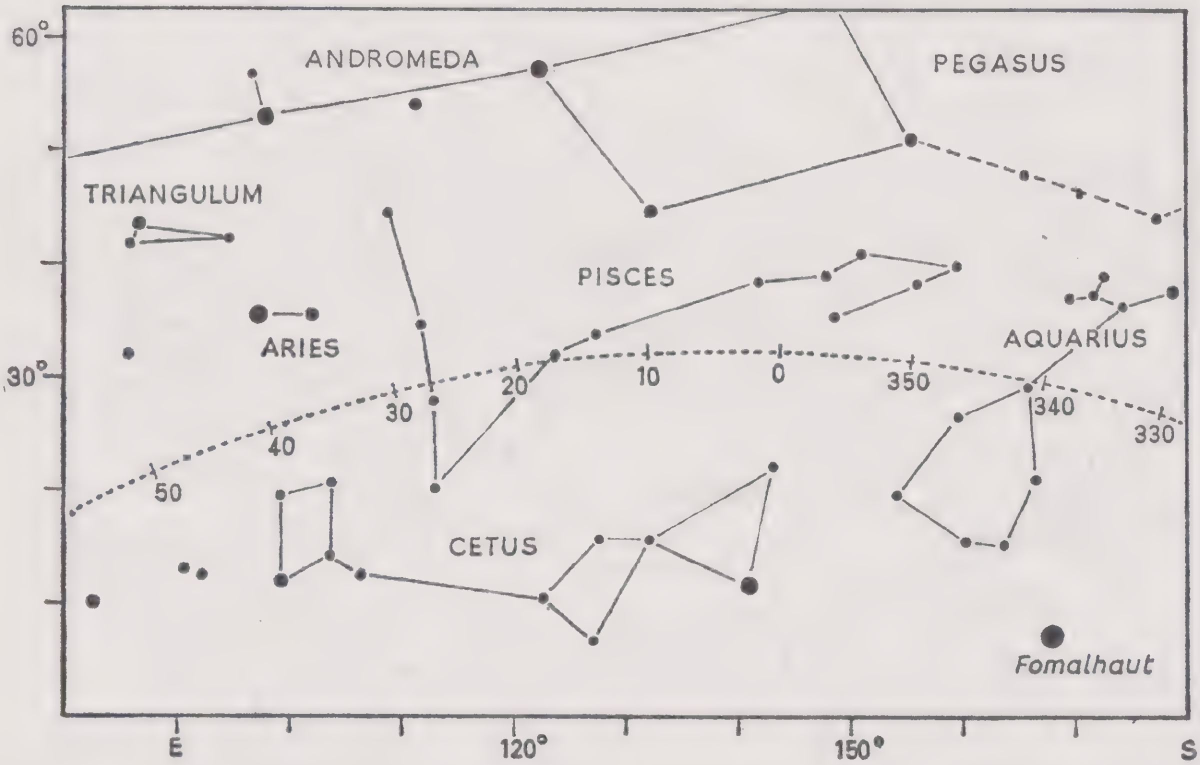
8R

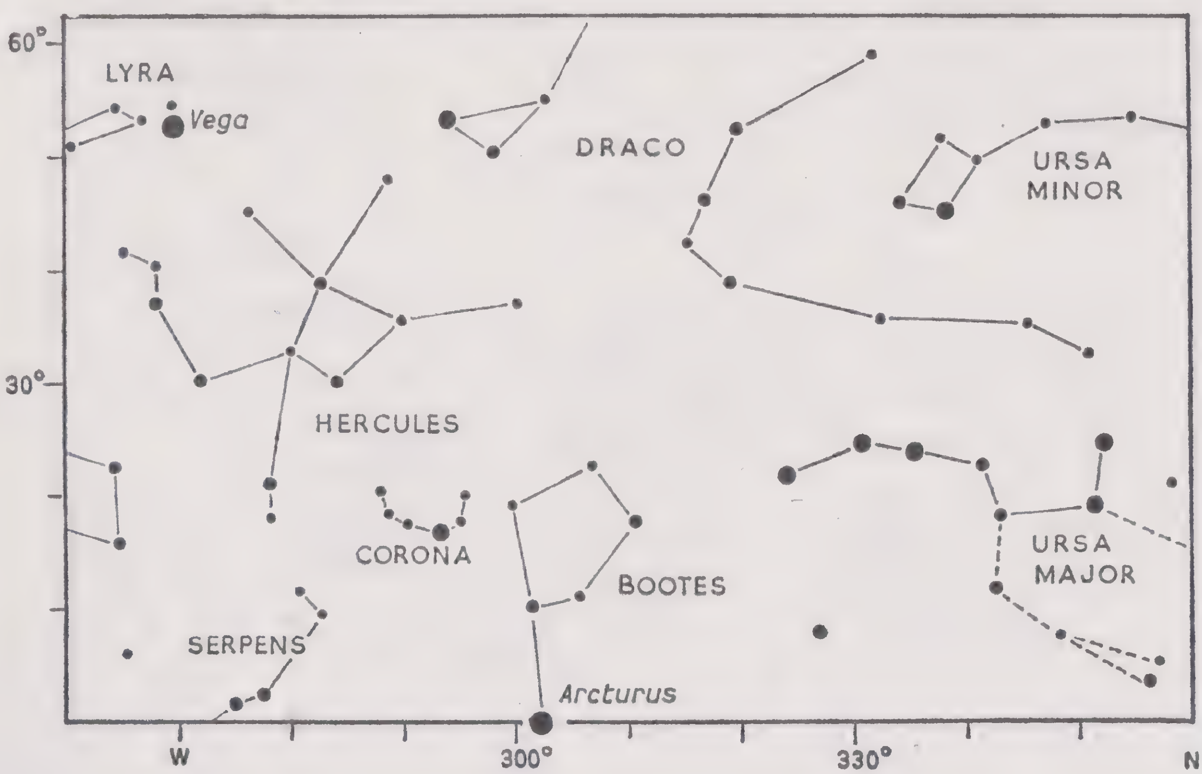




9L

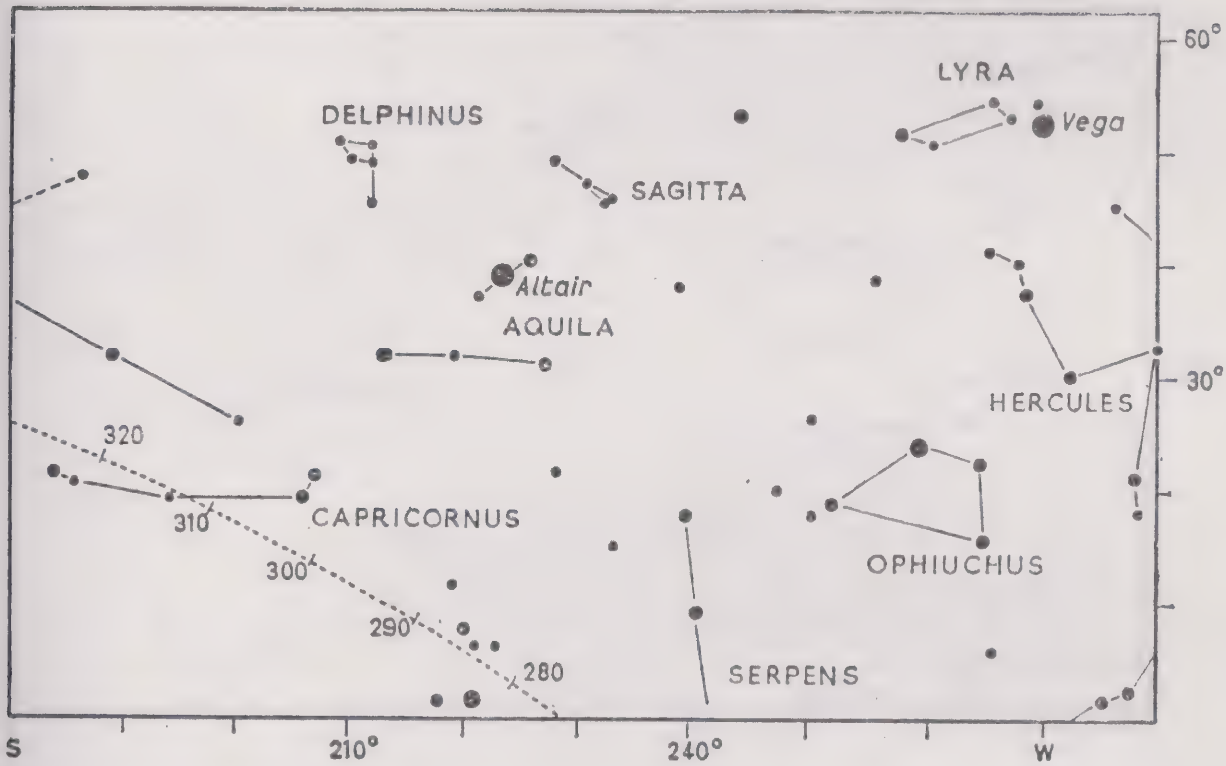
August 6 at 1^h	August 21 at midnight
September 6 at 23^h	September 21 at 22^h
October 6 at 21^h	October 21 at 20^h
November 6 at 19^h	November 21 at 18^h
December 6 at 17^h	December 21 at 16^h

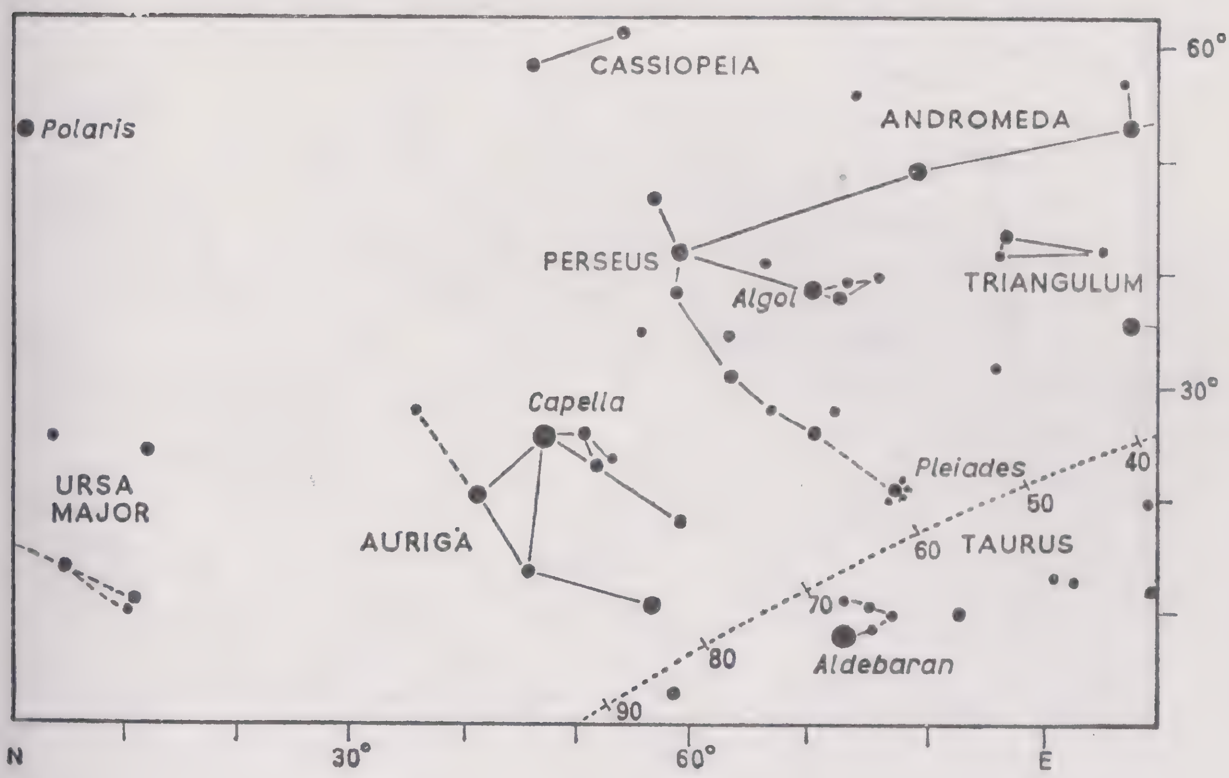




August	6	at	1^h	August	21	at	midnight
September	6	at	23^h	September	21	at	22^h
October	6	at	21^h	October	21	at	20^h
November	6	at	19^h	November	21	at	18^h
December	6	at	17^h	December	21	at	16^h

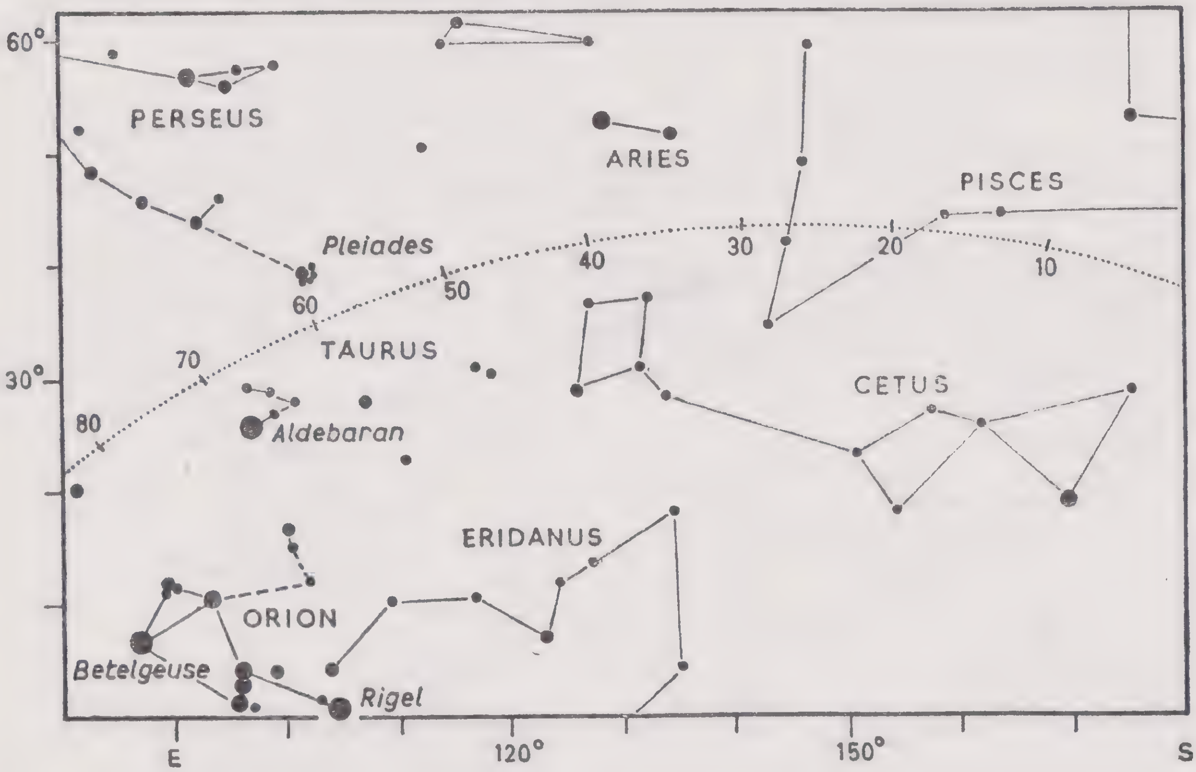
9R

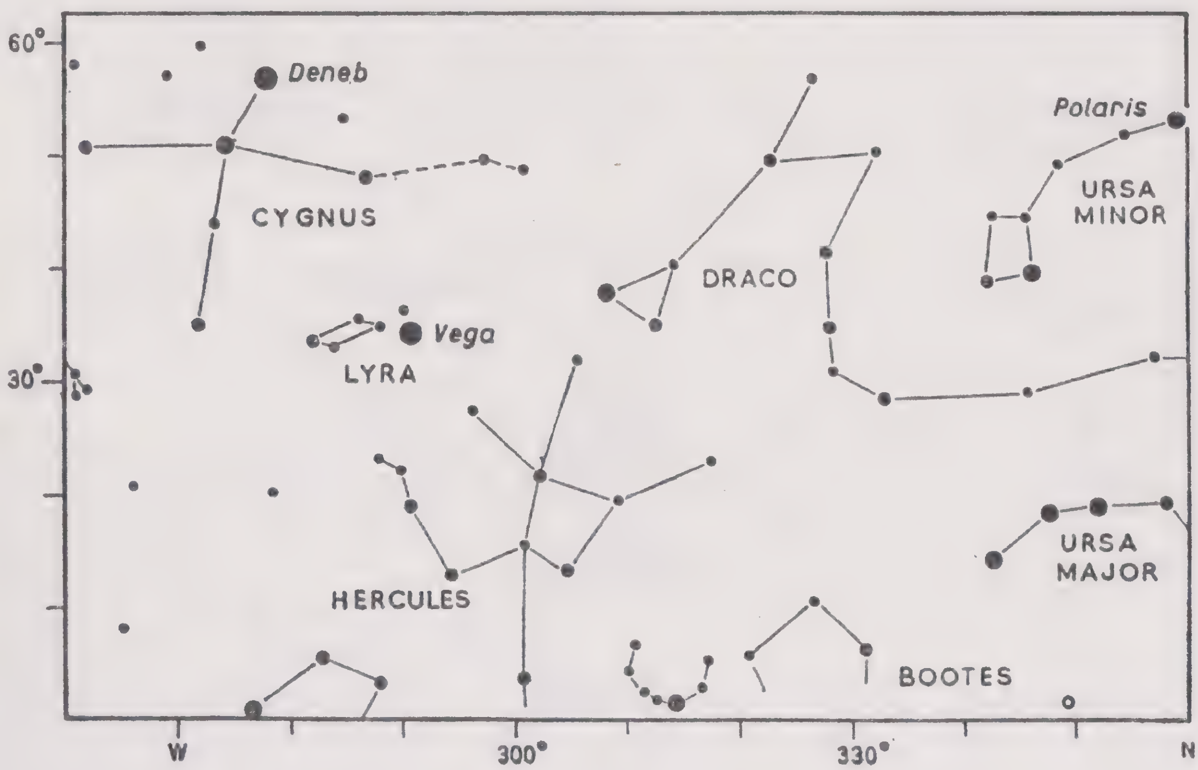




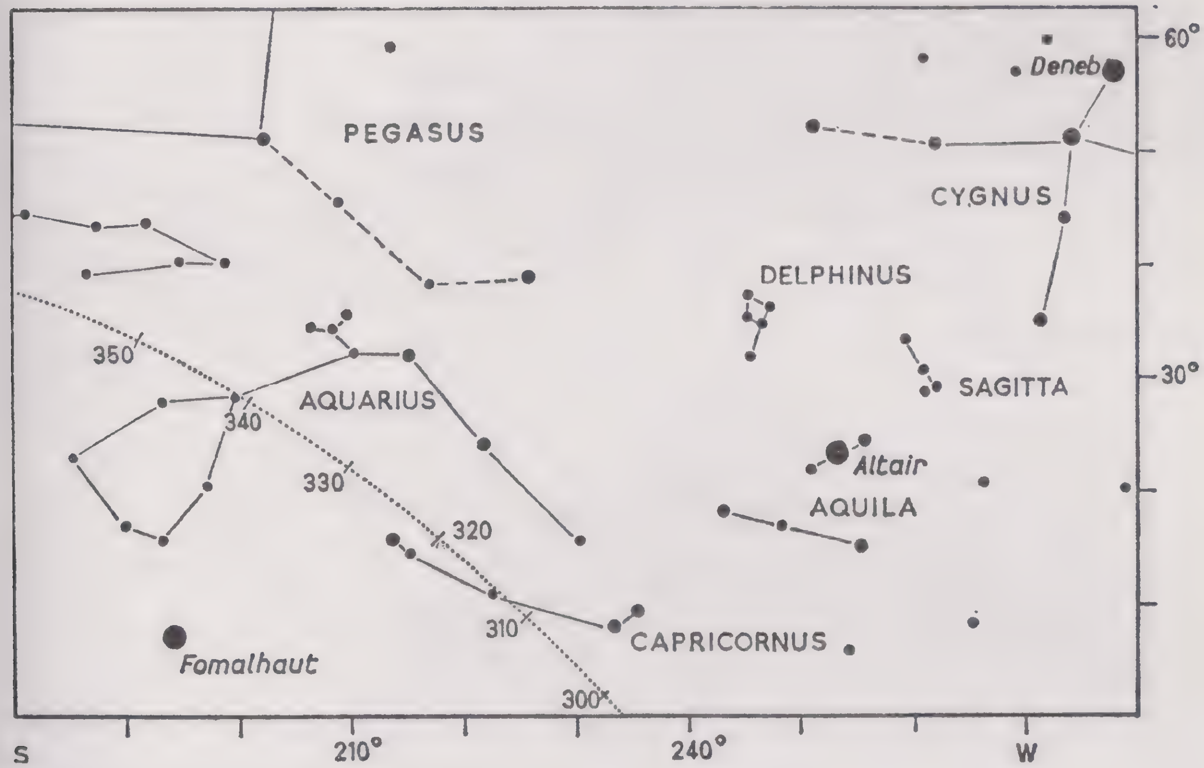
10L

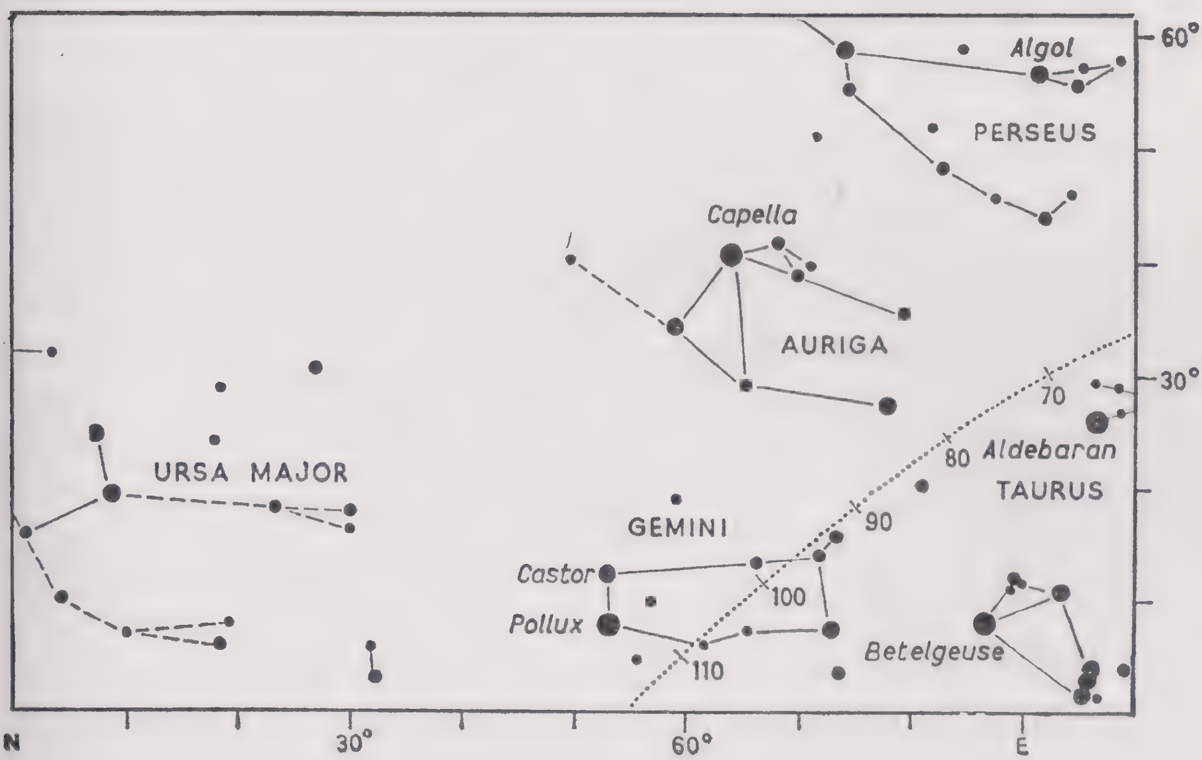
August 6 at 3^h	August 21 at 2^h
September 6 at 1^h	September 21 at midnight
October 6 at 23^h	October 21 at 22^h
November 6 at 21^h	November 21 at 20^h
December 6 at 19^h	December 21 at 18^h





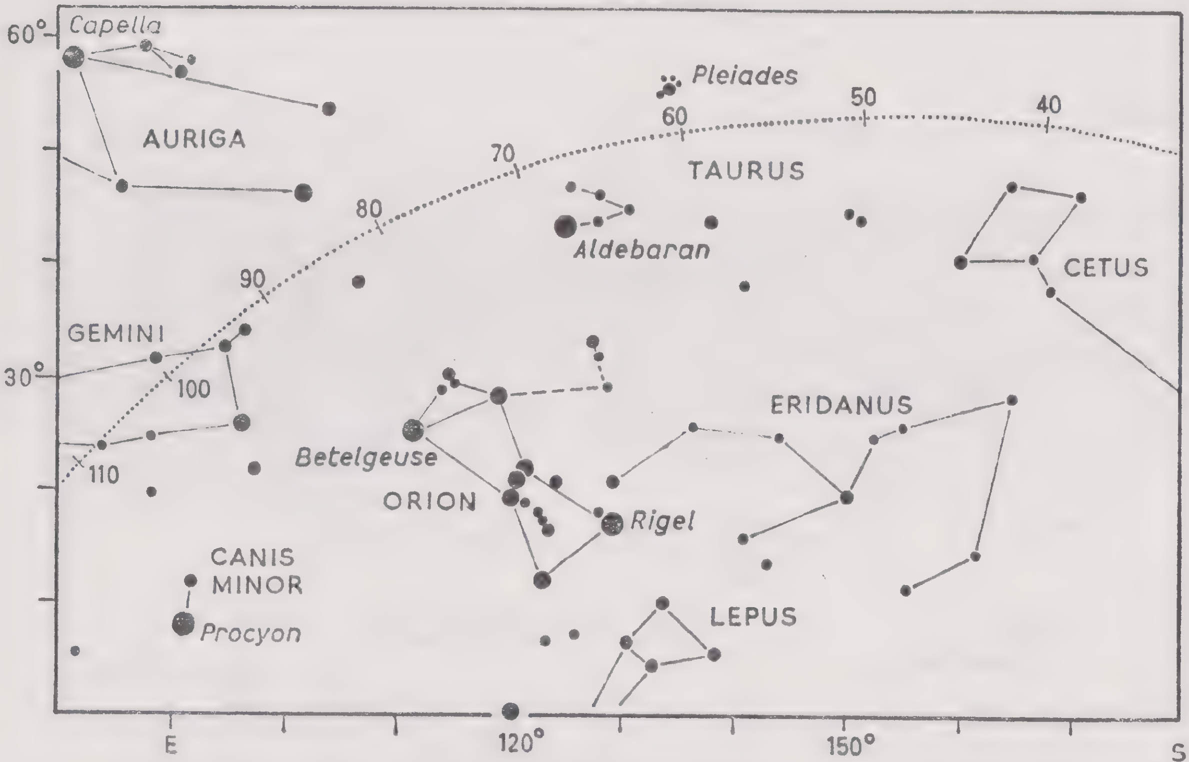
August 6 at 3^h	August 21 at 2^h	
September 6 at 1^h	September 21 at midnight	**10R**
October 6 at 23^h	October 21 at 22^h	
November 6 at 21^h	November 21 at 20^h	
December 6 at 19^h	December 21 at 18^h	

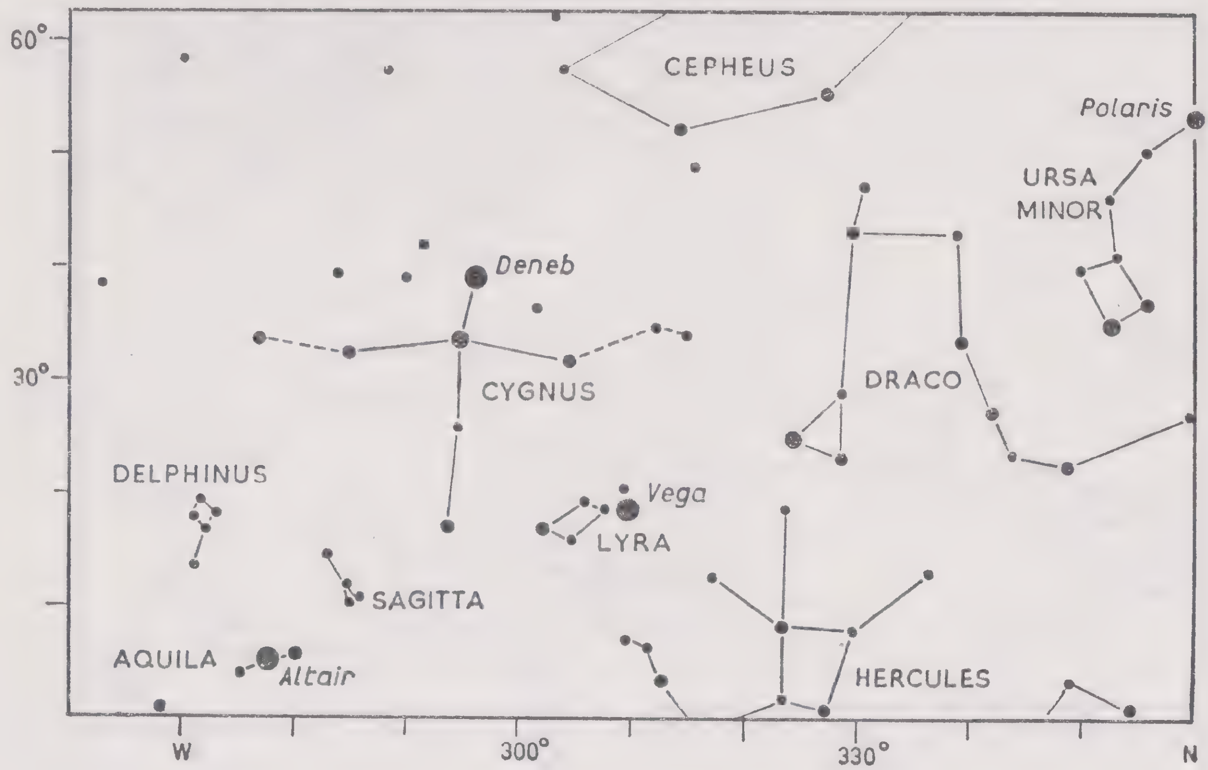




11L

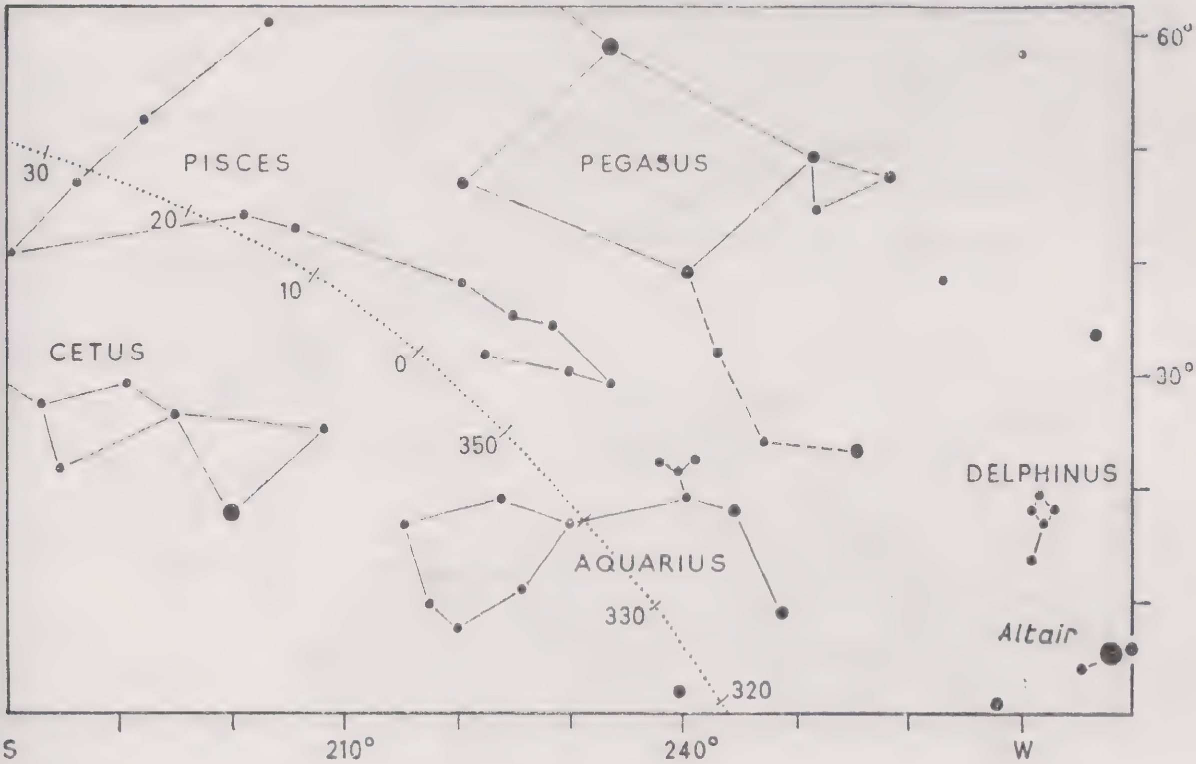
September	6	at	3^h	September	21	at	2^h
October	6	at	1^h	October	21	at	midnight
November	6	at	23^h	November	21	at	22^h
December	6	at	21^h	December	21	at	20^h
January	6	at	19^h	January	21	at	18^h

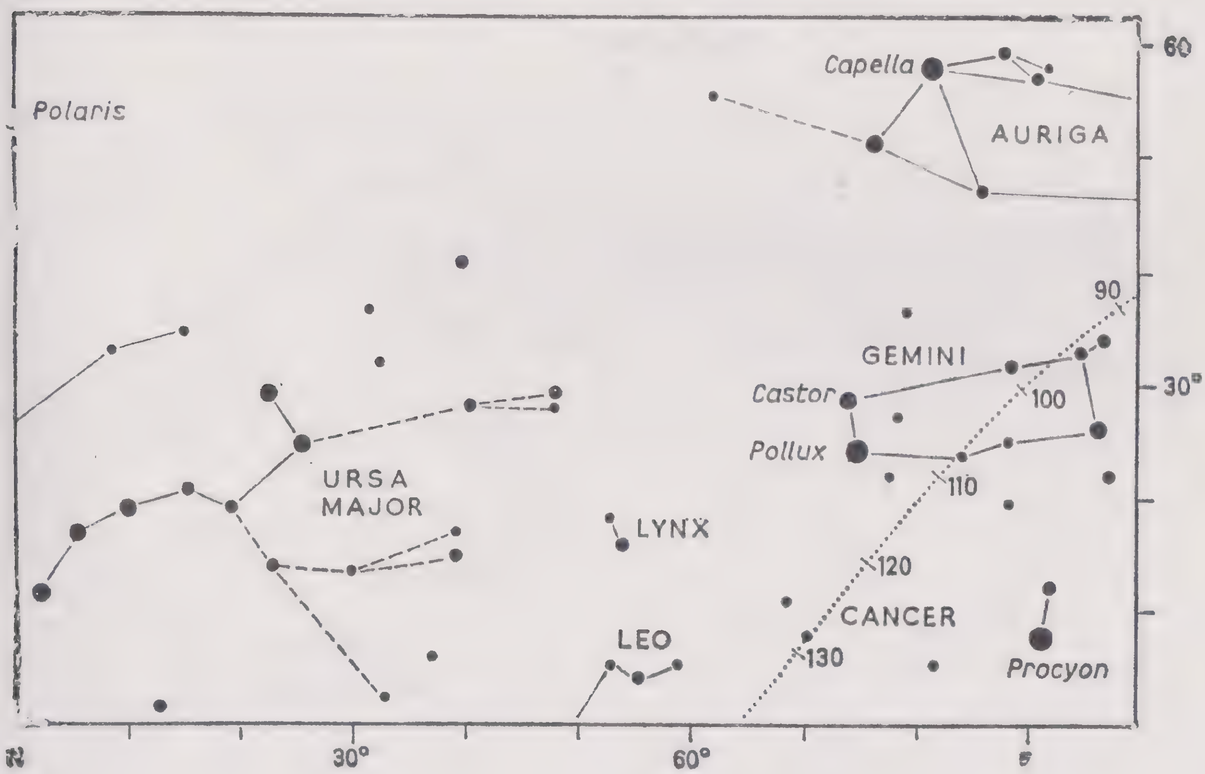




September	6	at	3^h		September	21	at	2^h	
October	6	at	1^h		October	21	at	midnight	
November	6	at	23^h		November	21	at	22^h	
December	6	at	21^h		December	21	at	20^h	
January	6	at	19^h		January	21	at	18^h	

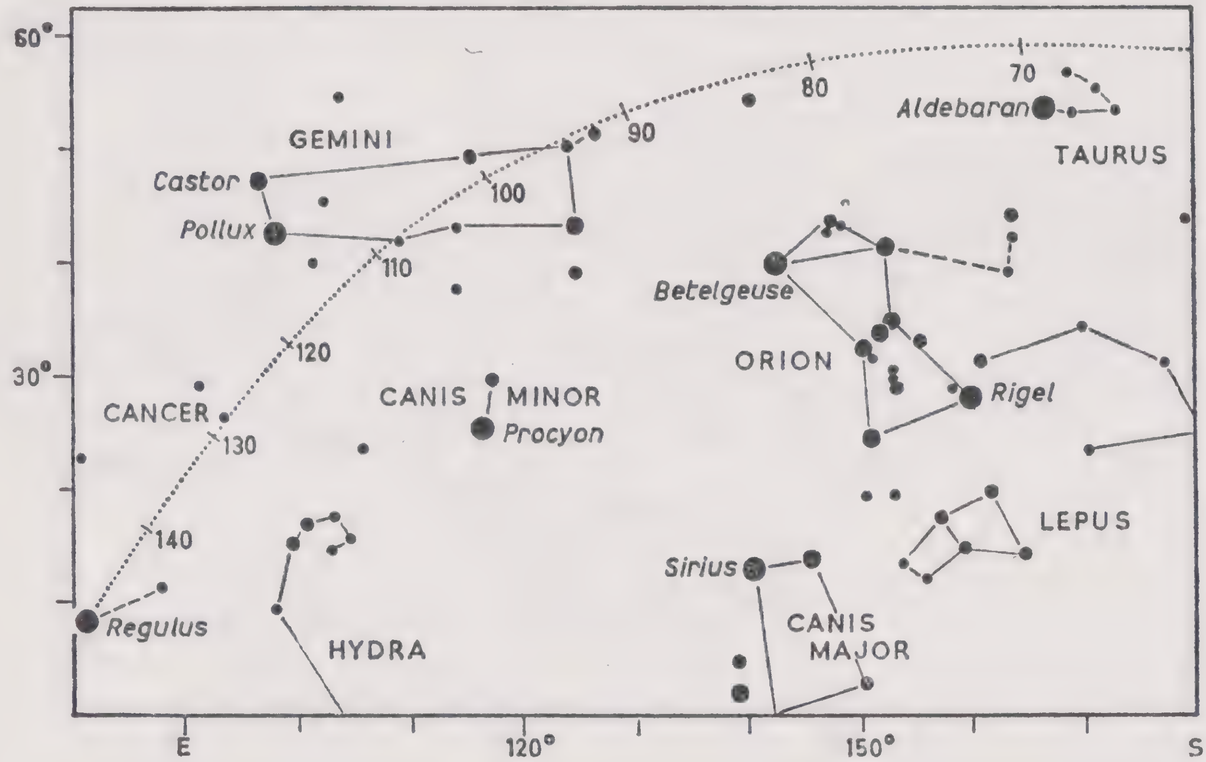
11R

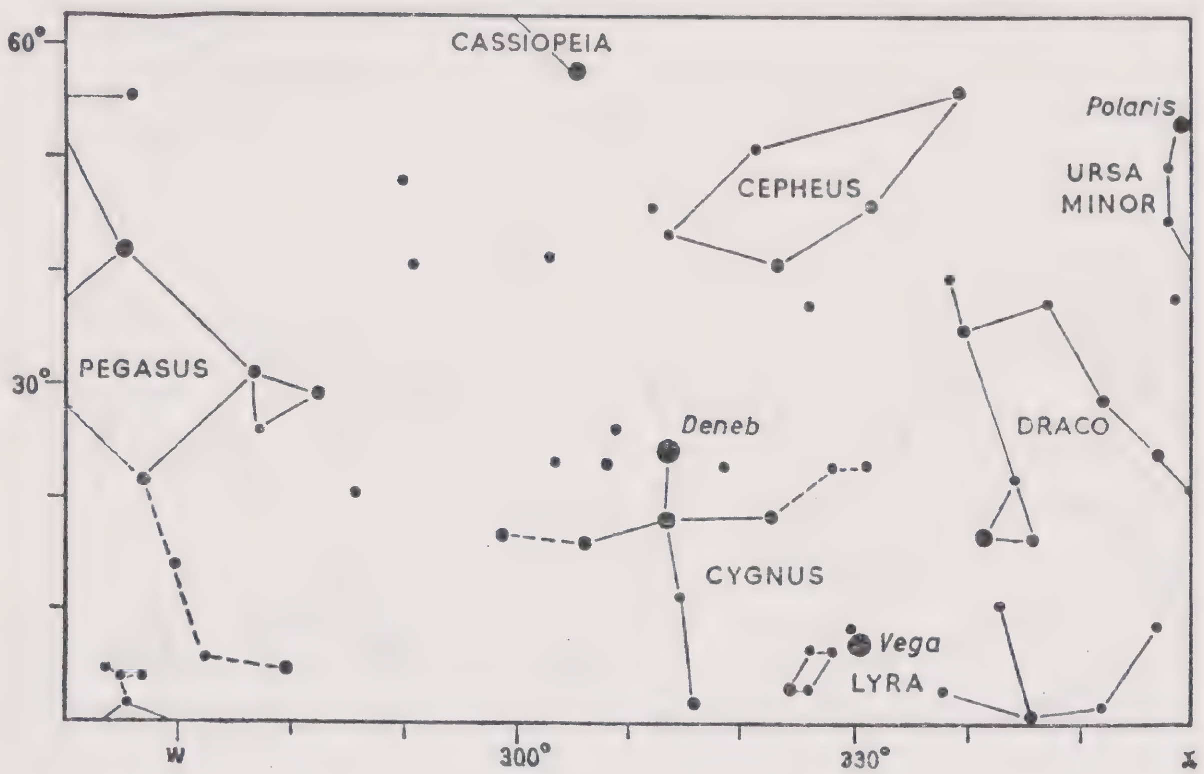




12L

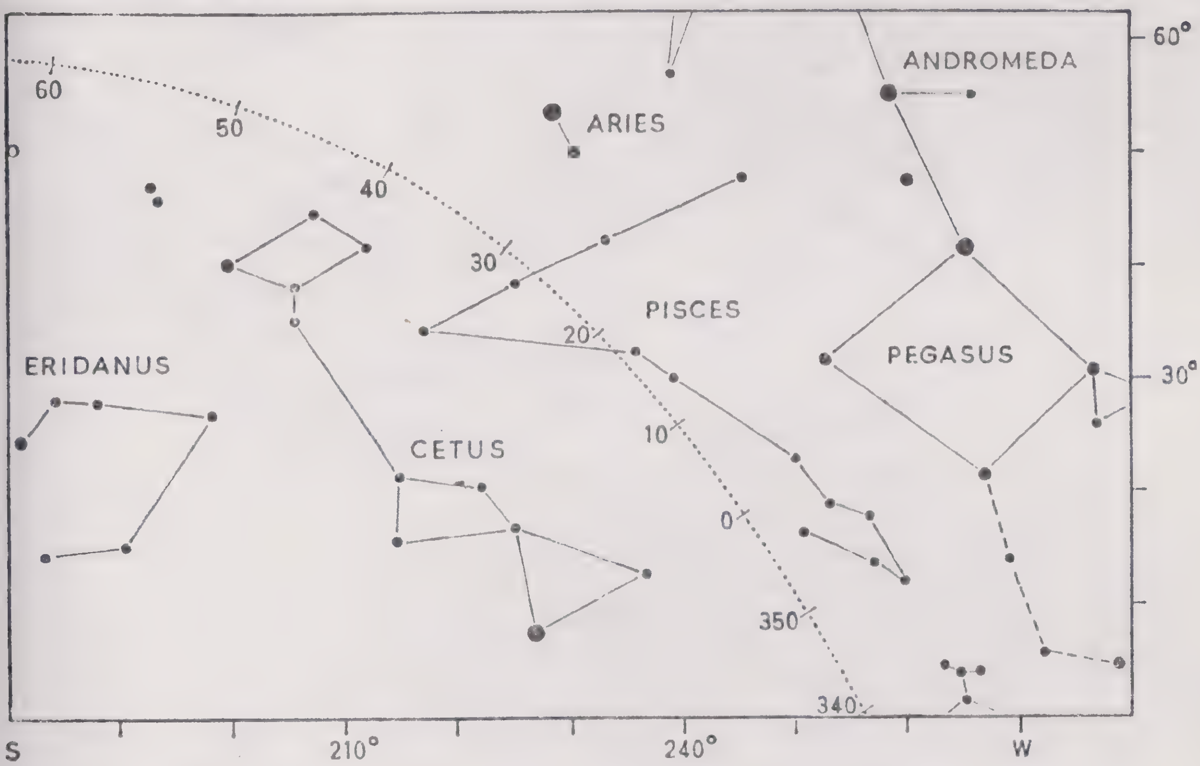
October 6 at 3^h	October 21 at 2^h
November 6 at 1^h	November 21 at midnight
December 6 at 23^h	December 21 at 22^h
January 6 at 21^h	January 21 at 20^h
February 6 at 19^h	February 21 at 18^h

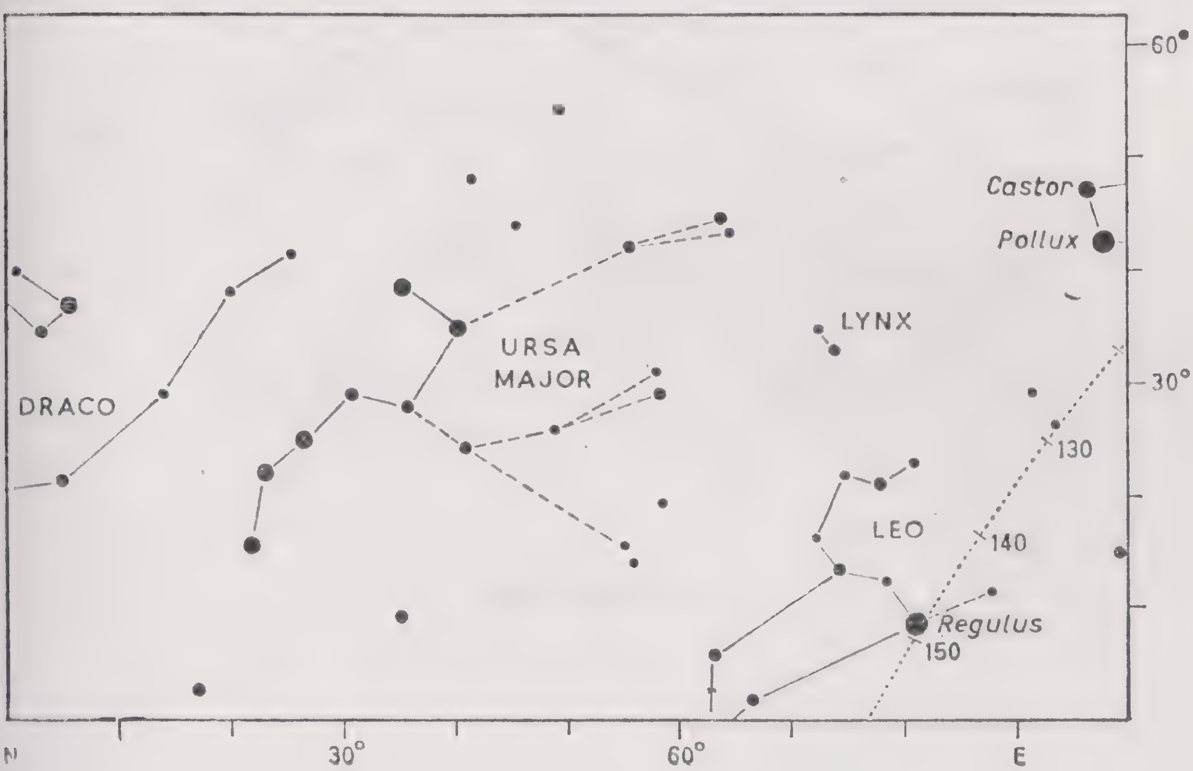


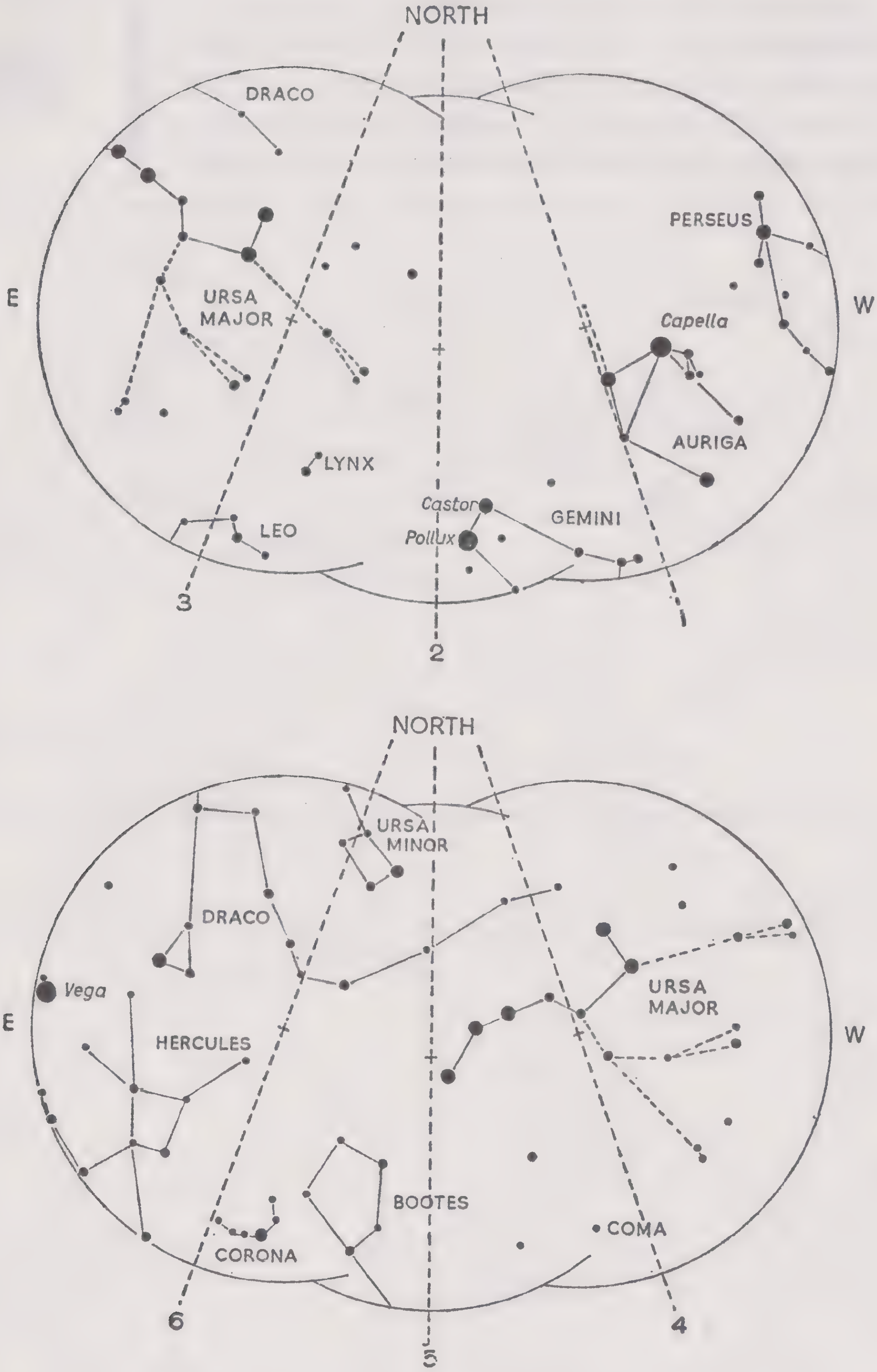


October 6 at	3^h	October 21 at	2^h
November 6 at	1^h	November 21 at	midnight
December 6 at	23^h	December 21 at	22^h
January 6 at	21^h	January 21 at	20^h
February 6 at	19^h	February 21 at	18^h

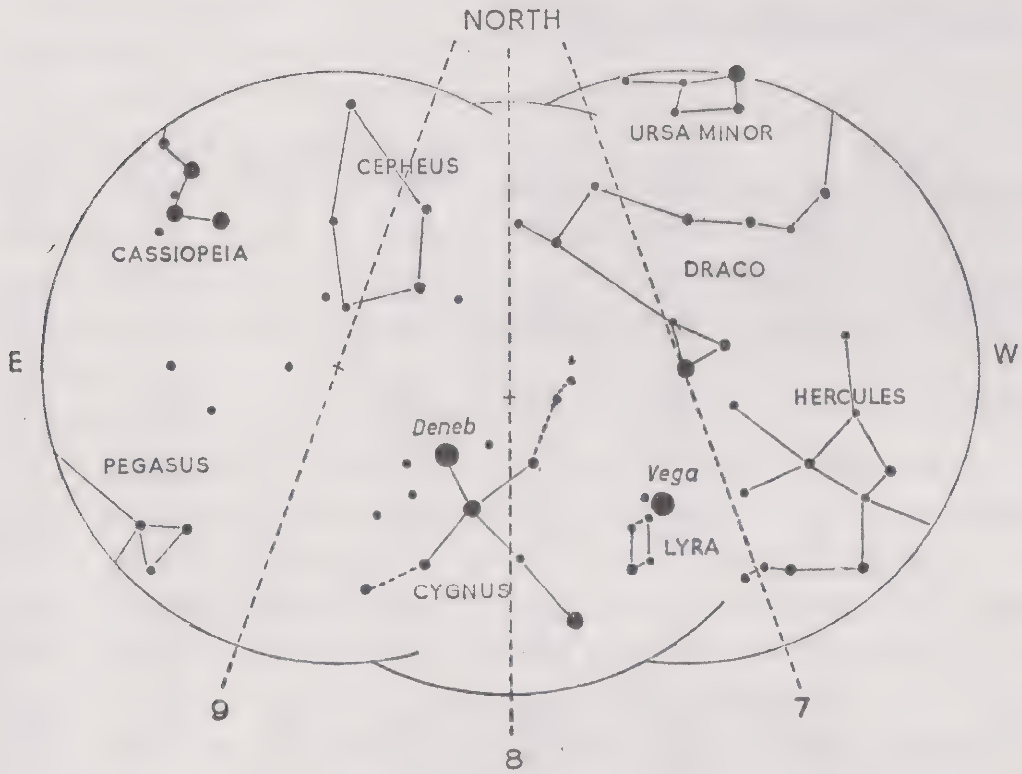
12R

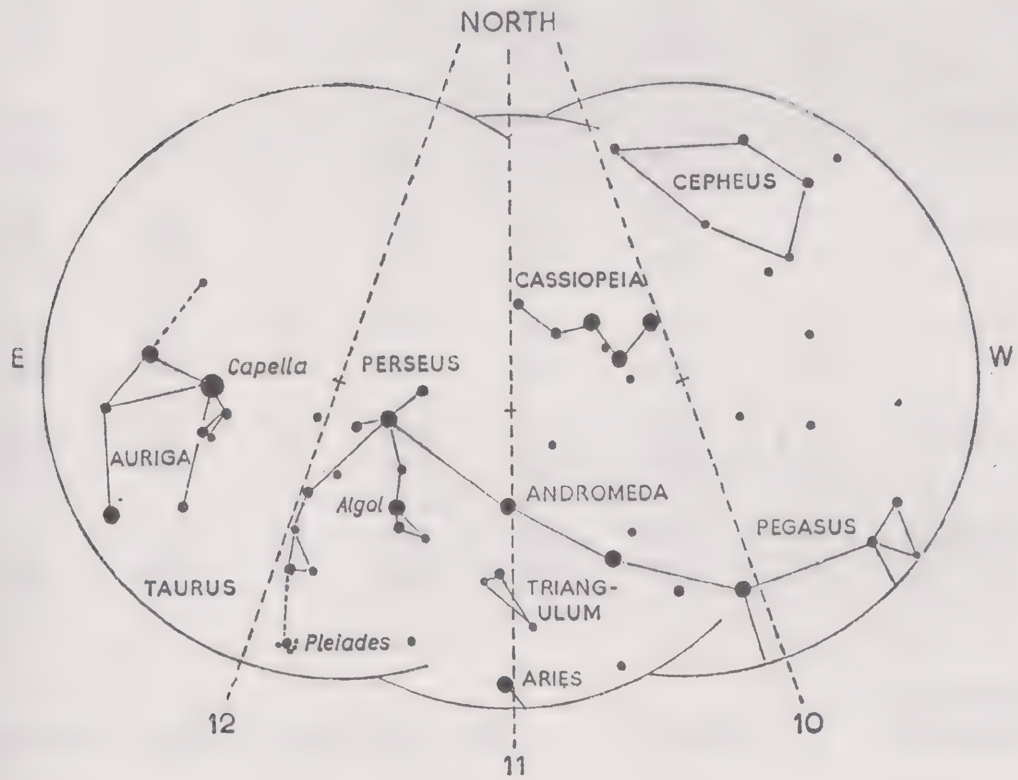






Overhead stars





Overhead stars

The Planets in 1971

DATE		*Venus*	*Mars*	*Jupiter*	*Saturn*	*Uranus*	*Neptune*
January	6	240°	229°	239°	47°	194°	242°
	21	254	239	241	46	194	243
February	6	270	249	244	47	194	243
	21	287	258	245	47	193	243
March	6	302	266	246	48	193	243
	21	320	275	247	50	192	243
April	6	339	285	246	51	192	243
	21	357	293	245	53	191	243
May	6	16	301	244	55	190	243
	21	34	309	242	57	190	242
June	6	53	316	240	59	190	242
	21	71	321	238	61	190	241
July	6	89	324	237	62	190	241
	21	107	323	237	64	190	241
August	6	127	320	237	65	191	241
	21	146	316	238	66	191	241
September	6	166	314	239	67	192	241
	21	184	314	241	67	193	241
October	6	203	318	244	67	194	241
	21	221	323	247	66	195	242
November	6	241	331	250	65	196	242
	21	260	339	253	64	197	243
December	6	279	347	257	63	198	243
	21	298	357	260	62	198	244
Conjunction: Superior		Aug. 27	—	Dec. 10	May 17	Oct. 7	Nov. 25
Opposition:		—	Aug. 10	May 23	Nov. 25	Apr. 1	May 23

Mercury moves so quickly among the stars that it is not possible to indicate its position on the star charts at a convenient interval. The monthly notes must be consulted for the best times at which the planet may be seen.

The positions of the other planets are given in the table on the opposite page. This gives the apparent longitudes on dates which correspond to those of the star charts, and the position of the planet may at once be found near the ecliptic at the given longitude.

Examples:

(1) *Where may Mars be found on the night of September* 10? From the table opposite the longitude of Mars at this time is found to be 314°. This position is shown for a September night on star charts 8L and 9R. The planet is therefore in the south in Capricornus, and sets in the south-west (chart 10R) just after midnight.

(2) *What is the bright planet seen high in the south-east at* 20^h *on Christmas Eve*? The south-eastern sky at this time is shown on star chart 11L, from which it is seen that the longitude of the planet must be about 60°. In the table opposite, the only planet in this position is Saturn.

The Planets and the Ecliptic

The paths of the planets about the Sun all lie close to the plane of the ecliptic, which is marked for us in the sky by the apparent path of the Sun among the stars, and is shown on the star charts by a broken line. The Moon and planets will always be found close to this line, never departing from it by more than about 7 degrees. Thus the planets are most favourably placed for observation when the ecliptic is well displayed, and this means that it should be as high in the sky as possible. This avoids the difficulty of finding a clear horizon. and also overcomes the problem of atmospheric absorption, which greatly reduces the light of the stars. Thus a star at an altitude of 10 degrees suffers a loss of 60 per cent of its light, which corresponds to a whole magnitude; at an altitude of only 4 degrees, the loss may amount to two magnitudes.

The position of the ecliptic in the sky is therefore of great importance, and since it is tilted at about 23½ degrees to the equator, it is only at certain times of the day or year that it is displayed to the best advantage. It will be realized that the Sun (and therefore the ecliptic) is at its highest in the sky at noon in midsummer, and at its lowest at noon in midwinter. Allowing for the daily motion of the sky, these times lead to the fact that the ecliptic is highest at midnight in winter, at sunset in the spring, at noon in summer and at sunrise in the autumn. Hence these are the best times to see the planets. Thus, if Venus is an evening star, in the western sky after sunset, it will be seen to best advantage if this occurs in the spring, when the ecliptic is high in the sky and slopes down steeply to the north-west. This means that the planet is not only higher in the sky, but will remain for a much longer period above the horizon. For similar reasons, a morning star will be seen at its best on

autumn mornings before sunrise, when the ecliptic is high in the east. The outer planets, which can come to opposition and are then in the south at midnight, are best seen when opposition occurs in the winter months. Clearly the summer is the least favourable time to observe the planets, for the ecliptic is always low in the sky on summer nights.

Notes on the Planets in the monthly diagrams

The following general notes on observing the planets are followed by detailed month-by-month accounts of the behaviour of the planets, and of other interesting phenomena. These monthly notes include diagrams of the apparent movements of the planets at favourable times of the year. Additional notes on other astronomical phenomena will be found on the following pages.

The inferior planets, Mercury and Venus, move in smaller orbits than that of the Earth, and so are always seen near the Sun. They are most obvious at the times of greatest angular distance from the Sun (greatest elongation), which may reach 28 degrees for Mercury, or 47 degrees for Venus. They are then seen as evening stars in the western sky after sunset (at eastern elongations) or as morning stars in the eastern sky before sunrise (at western elongations). The succession of phenomena, conjunctions and elongations, always follows the same order, but the intervals between them are not equal. Thus if either planet is moving round the far side of its orbit its motion will be to the east, in the same direction in which the Sun appears to be moving. It therefore takes much longer for the planet to overtake the Sun—that is, to come to superior conjunction—than it does when moving round to inferior conjunction, between Sun and Earth. The intervals given in the following table are average values; they remain fairly constant in the case of Venus, which travels in an almost circular orbit. In the case of Mercury, however, conditions vary widely because of the great eccentricity and inclination of the planet's orbit.

		Mercury	*Venus*
Inferior conj.	to Elongation West	22 days	72 days
Elongation West	to Superior conj.	36 days	220 days
Superior conj.	to Elongation East	36 days	220 days
Elongation East	to Inferior conj.	22 days	72 days

The greatest brilliancy of Venus always occurs about a month *before* greatest western elongation (as a morning star), or a month *after* greatest eastern elongation (as an evening star). No such rule can be given for Mercury, because its distance from Sun and Earth can vary over a wide range.

Mercury is not likely to be seen unless a clear horizon is available; it is seldom seen as much as 10 degrees above the horizon in the twilight sky. In general it may be said that the most favourable times for seeing Mercury as an evening star will be in spring, some days before greatest eastern elongation; in autumn it may be seen as a morning star some days after greatest western elongation.

Venus is the brightest of the planets, and may be seen on occasions in broad daylight. Like Mercury, it is alternately a morning and an evening star, and will be highest in the sky when it is a morning star in autumn, or an evening star in spring. Venus is seen to best advantage when it comes to greatest eastern elongation in June; it is then well north of the Sun in the spring months and is a brilliant object in the sunset sky over a long period.

The superior planets, which travel in orbits larger than that of the Earth, differ from Mercury and Venus in that they can be seen opposite the Sun in the sky. The superior planets are morning stars after conjunction with the Sun, rising earlier each day until they come to opposition. They will then be in the south at midnight, and visible all night. After opposition, they are evening stars, setting earlier each evening until they set in the west with the Sun at the next conjunction. The interval between conjunctions or between oppositions is greatest for Mars (over two years). At the time of opposition, the planet is nearest the Earth, and therefore at its brightest. This change in brightness is most

noticeable with Mars, whose distance from the Earth can vary considerably; the other superior planets are at such great distances that there is very little change in brightness from one opposition to another. The effect of altitude is, however, of importance, for at a December opposition the planet will be among the stars of Taurus or Gemini, and can then be at an altitude of more than 60 degrees in southern England. At a summer opposition, when the planet is in Sagittarius, it may only rise to about 15 degrees above the southern horizon, and so make a less impressive appearance.

Mars, whose orbit is appreciably eccentric, comes nearest to the Earth at an opposition at the end of August; it may then be brighter even than Jupiter, but rather low in the sky in Aquarius. These favourable oppositions occur every fifteen or seventeen years (1924, 1941, 1956, 1971), but in this country the planet is probably better seen at an opposition in the autumn or winter, when it is higher in the sky. Oppositions of Mars occur at an average interval of 780 days, and during this time the planet makes a complete circuit of the sky.

Jupiter is always a bright planet, and comes to opposition a month later each year, having moved, roughly speaking, from one Zodiacal constellation to the next.

Saturn moves much more slowly than Jupiter, and may remain in the same constellation for several years. The brightness of Saturn depends on the aspect of its rings, as well as on the distance from Earth and Sun. The rings are now well open, and the planet is growing brighter at each opposition.

Uranus, Neptune and *Pluto* are hardly likely to attract the attention of observers without adequate instruments, but some notes on their present positions in the sky will be found in the April and May notes.

Phases of the Moon, 1971

New Moon	d h m	*First Quarter*	d h m	*Full Moon*	d h m	*Last Quarter*	d h m
Jan.	26 22 55	Jan.	4 04 55	Jan.	11 13 20	Jan.	19 18 08
Feb.	25 09 49	Feb.	2 14 31	Feb.	10 07 41	Feb.	18 12 14
Mar.	26 19 24	Mar.	4 02 01	Mar.	12 02 34	Mar.	20 02 14
Apr.	25 04 02	Apr.	2 15 46	Apr.	10 20 10	Apr.	18 12 58
May	24 12 32	May	2 07 34	May	10 11 24	May	17 20 15
June	22 21 57	June	1 00 42	June	9 00 04	June	16 01 24
July	22 09 15	June	30 18 11	July	8 10 37	July	15 05 47
Aug.	20 22 53	July	30 11 07	Aug.	6 19 42	Aug.	13 10 55
Sept.	19 14 42	Aug.	29 02 56	Sept.	5 04 03	Sept.	11 18 23
Oct.	19 07 59	Sept.	27 17 17	Oct.	4 12 20	Oct.	11 05 29
Nov.	18 01 46	Oct.	27 05 54	Nov.	2 21 20	Nov.	9 20 51
Dec.	17 19 03	Nov.	25 16 37	Dec.	2 07 48	Dec.	9 16 02
		Dec.	25 01 35	Dec.	31 20 20		

All times are G.M.T.

MONTHLY NOTES, 1971

January

Full Moon: 11 January *New Moon*: 26 January

Earth is at perihelion (nearest to the Sun) on 4 January, at a distance of 91,400,000 miles (147,100,000 km.).

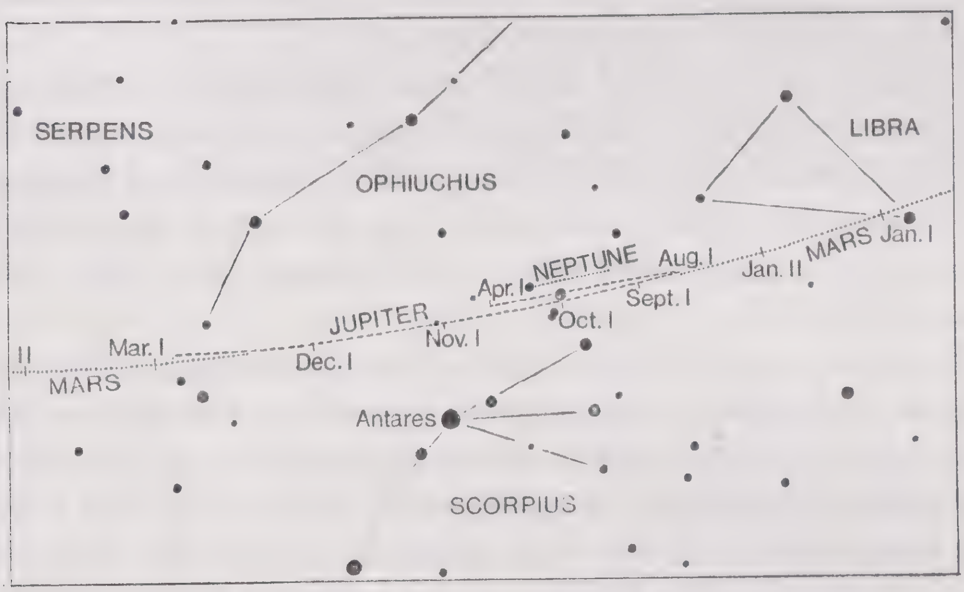
Mercury is at greatest western elongation on 19 January (24°) and it may then be possible to see it low down near the horizon in the south-east before dawn.

Venus is a morning star, rising about four hours before the Sun at the beginning of the year and coming to greatest western elongation on 20 January (47°). Venus passes 3° north of Jupiter on 4 January and these two planets, together with Mars, form an interesting and rapidly changing pattern in the south-eastern sky before dawn. Venus is a brilliant object (magnitudes $-4{\cdot}3$ to $-4{\cdot}0$) at present, and may be seen against a dark sky, but on the whole it will not be a very impressive object during the year.

Mars is a morning star, rising about 4h. in the south-east, and visible in the south at sunrise. It is moving direct in Libra, passing close to Alpha Libræ (Zuben-el-Genubi) at the beginning of January. At the end of the month it passes into Scorpius, and is in close conjunction with Jupiter on 26 January, Mars being then less than a third of a degree south of Jupiter, although very much fainter than the giant planet. (Magnitude of Mars $+1{\cdot}7$ to $+1{\cdot}4$ during the month.) This year's opposition of Mars is one of the main events of 1971, the planet coming closer to the Earth than at any time during the past fifteen years. The diagram below includes the apparent path of Mars from the beginning of the year until the middle of March.

Jupiter is also a morning star in Libra, moving into Scorpius at the end of the month. It will be seen in the south-east before dawn together with the planets Venus and Mars. These are moving more rapidly than Jupiter, and Venus passes north of Jupiter on 4 January, while Mars makes a close approach to the south of Jupiter on 26 January. Although never as bright as Venus, Jupiter is a brilliant and unmistakable object; it grows a little brighter during the month (magnitude −1·3 to −1·5).

Saturn is an evening star, setting in the west in the early morning hours. It is moving retrograde in Aries at the beginning of the year, but reaches a stationary point on 18 January, and then begins to move direct (see diagram on page 96) Saturn is still a very bright object, (magnitude +0·2 to +0·4) and there are no bright stars in the neighbourhood.



Jupiter, Mars and Neptune

The Colours of the Planets All the bright planets are visible this month at various times in the night, so that their colours may be compared; it is these colours which led, in part at least,

to the names of the planets. There is certainly no doubt about Mars. Its redness is striking even when, as at present, it is relatively distant from the Earth, and is not so bright as the average first-magnitude star. It is easy to understand why the ancients named it after the God of War; red suggests blood.

There have been suggestions that the colour of Mars is due to effects produced by the planet's atmosphere, but these ideas are now known to be wrong. The red hue is produced by the surface material, which may be some coloured mineral such as felsite or limonite.

Mercury, elusive and quick-moving, was appropriately named in honour of the Messenger of the Gods. When visible with the naked eye it is always low over the horizon, and so it seems to twinkle obviously (the popular notion that planets can never twinkle is wrong, though it is true that a planet, which shows up as a small disk, scintillates less than a star, which is to all intents and purposes a point source). It is said that Mercury is pinkish, but the colour is not pronounced even when the planet is seen through a telescope.

Venus is creamy, and is the most beautiful of the planets—when seen with the naked eye. Certainly it is well named after the Goddess of Beauty. Telescopically, Venus is a disappointment, but the slightly yellowish hue can often be noticeable, even though when well above the horizon the disk is often described as entirely colourless.

The giant outer planets. Jupiter and Saturn, are both strongly yellow. In the case of Jupiter the hue is not noticeable with the naked eye, but Saturn looks decidedly 'leaden', and was regarded as baleful; the ancients could have no idea that Saturn is in fact the least dense and the most beautiful of all the members of the Sun's family. The rings are more reflective than the disk, and so during 1970, with the rings opening out, the planet will be brighter than it has been at any time during the past seven years; it is in the northern hemisphere of the sky, and so will be excellently placed for observers in Europe and the United States.

Of the three telescopic planets Uranus (dimly visible with the

naked eye when at its best) is greenish, and Neptune has a bluish cast. Pluto is said to be rather yellow, but it is so faint that ordinary-sized telescopes used by amateurs will show it only as a colourless dot.

Incidentally, the names we use for the planets are Roman, though the gods and goddesses themselves are Greek. (When Rome became dominant, the Greek deities were simply taken over, though sometimes wih minor alterations.) The Greek names still survive in astronomy; for instance, 'Martian geography' is known as areography (Greek, Ares—the war-god), while with Jupiter we still meet with the term 'zenocentric', from the Greek name Zeus—the ruler of Olympus.

Eridanus, the River One of the longest constellations in the sky is Eridanus, the River, which was one of Ptolemy's original forty-eight groups. In length it is exceeded only by the vast, faint Hydra. Eridanus begins with Kursa (Beta Eridani) in the neighbourhood of Rigel, and sprawls down southward, passing over the horizon of Europe and the northern United States. Both its two most interesting stars lie in the southern part of the constellation. Theta Eridani (Acamar), a splendid double star, was ranked as of the first magnitude by the old observers of more than a thousand years ago, and there seems excellent evidence that it has faded considerably—though the ancient records are not entirely reliable, and one must be wary of jumping to conclusions. Alpha Eridani (Achernar) lies at the southernmost extremity of the River, in the area of the south celestial pole; its magnitude is 0·5, so that it is one of the most brilliant stars in the sky. It is white, and is 200 times as luminous as the Sun. Its distance from us is 66 light-years.

February

Full Moon: 10 February *New Moon*: 25 February

Mercury is moving towards superior conjunction and is too close to the Sun to be seen.

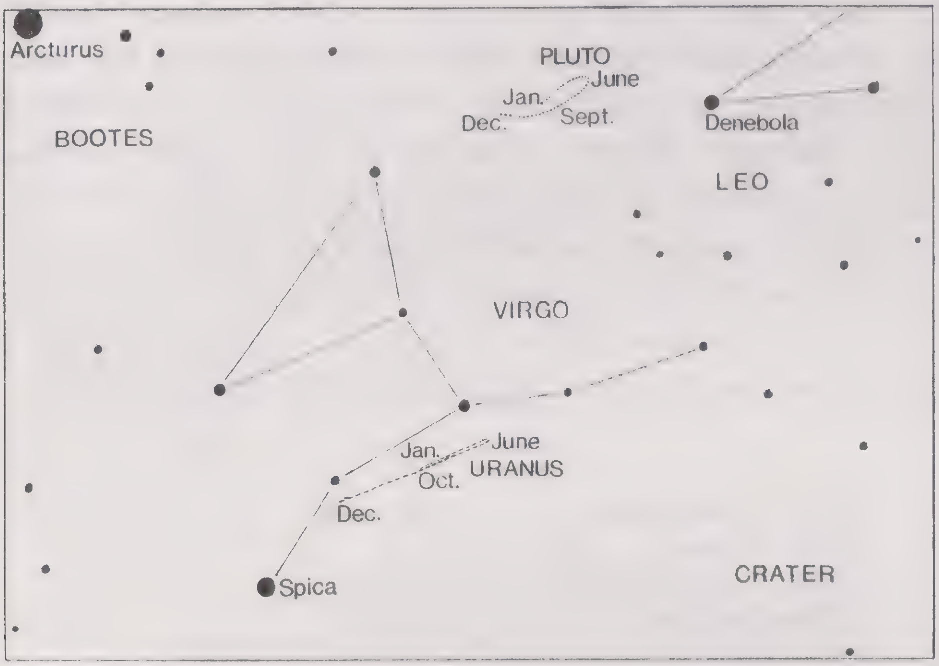
Venus is still a morning star, rising in the south-east about three hours before the Sun. It continues to fade (magnitude –4·0 to –3·7) as its distance from the Earth increases.

Mars is a morning star, rising about 3h. in the south-east in Scorpius. The planet continues to grow brighter as it comes nearer to the Earth (magnitude +1·4 to +1·1). On 5 February, Mars passes about five degrees north of *Antares* (the 'rival of Mars') and this will be a very good opportunity to compare the colours of the two objects, as they are of about the same magnitude (Mars +1·3, *Antares* +1·2). Mars at this time is actually in the constellation Ophiuchus, which at this point intrudes into the Zodiac. In the diagram on page 55 the path of Mars follows closely that of Jupiter, the scale of the diagram being too small to show the separation between the two.

Jupiter rises in the early morning hours among the bright stars of Scorpius, but it is a brilliant object (magnitude –1·5 to –1·7) and is quite unmistakable. Jupiter passes less than a degree south of Neptune on 2 February, and this is the first of three such conjunctions of the two planets during the year. Keen observers will also notice the very close approach of Jupiter to the star Beta Scorpii (magnitude 2·9) on 11 February.

Saturn sets at midnight at the end of February and remains at about the same brightness (magnitude +0·4). It will be seen some degrees south of the Moon at First Quarter on 2 February,

Saturn at this time being south of the ecliptic and the Moon well north of it.



Uranus and Pluto, 1970

A total eclipse of the Moon occurs in the early morning of 10 February, but only the beginning will be seen from the British Isles, shortly before sunrise. (See notes on page 103.)

A partial eclipse of the Sun on 25 February will be visible in the morning of 25 February (see notes on page 103).

Proper Names of the Stars In 1603, Johann Bayer introduced his system of stellar nomenclature, according to which every bright star was allotted a Greek letter; thus the brightest star in Auriga became Alpha Aurigæ, the second brightest Beta Aurigæ, and so on. Because there are only twenty-four Greek letters the system is limited, but it has been retained; in addition to its Greek letter each star has a number, assigned to it by Flamsteed in the late 17th century. (Flamsteed was appointed astronomer at Greenwich in 1675 so that he could compile a

new star catalogue for the use of British marine navigators. The task took many years, and the final version was not published until after Flamsteed's death.)

The stars have also been given proper names. These are chiefly Arabic, but some of them are appropriate; for instance, Antares (Alpha Scorpii), which is very red, is called 'the Rivel of Ares' (Mars). However, many of the proper names are cumbersome, and have dropped out of use except for the first-magnitude stars and a few others, such as Mira (Omicron Ceti, the famous long-period variable) and Mizar (Zeta Ursæ Majoris, the binary in the Great Bear). It may be of interest to list some of the names, beginning with those still in common use:

Alpha Andromedæ:	Alpheratz
Alpha Aquilæ:	Altair
Alpha Argûs (Carinæ):	Canopus
Alpha Aurigæ:	Capella
Alpha Boötis:	Arcturus
Alpha Canum Venaticorum:	Cor Caroli
Alpha Canis Majoris:	Sirius
Alpha Canis Minoris:	Procyon
Omicron Ceti:	Mira
Alpha Cygni:	Deneb
Beta Cygni:	Albireo
Alpha Draconis:	Thuban
Alpha Eridani:	Achernar
Alpha Geminorum:	Castor
Beta Geminorum:	Pollux
Alpha Hydræ:	Alphard
Alpha Leonis:	Regulus
Alpha Lyræ:	Vega
Alpha Orionis:	Betelgeux
Beta Orionis:	Rigel
Beta Persei:	Fomalhaut
Alpha Piscis Austrini:	Algol
Alpha Scorpii:	Antares
Alpha Tauri:	Aldebaran
Eta Tauri:	Alcyone
Alpha Ursæ Majoris:	Dubhe
Zeta Ursæ Majoris:	Mizar
Alpha Ursæ Minoris:	Polaris
Beta Ursæ Minoris:	Kocab
Alpha Virginis:	Spica

Some of these stars have alternative proper names. Alpheratz is sometimes called Sirrah, while Betelgeux may be spelled in various different ways (Betelgeuse and Betelgeuze are other forms). On the other hand, there are a few brilliant stars which have no old proper names; Alpha Centauri and Alpha Crucis are examples of this, though air navigators call them 'Rigel Kent' and 'Acrux' respectively.

To give a full list of other names, most of which are in disuse, would be tedious, but the following selection may be of interest.

Alpha Aquarii:	Sadalmelik
Gamma Aquilæ:	Tarazed
Alpha Arietis:	Hamal
Beta Aurigæ:	Menkarlina
Mu Boötis:	Alkalurops
Alpha Cassiopeiæ:	Shedir
Alpha Cephei:	Alderamin
Beta Ceti:	Diphda
Alpha Coronæ Borealis:	Alphekka (or Gemma)
Delta Draconis:	Taïs
Gamma Eridani:	Zaurak
Tau Eridani:	Angetenar
Gamma Geminorum:	Alhena
Alpha Gruis:	Alnair
Alpha Herculis:	Rasalgethi
Beta Herculis:	Kornephoros
Zeta Herculis:	Rutilicus
Beta Leonis:	Denebola
Alpha Libræ:	Zubenelgenubi
Alpha Ophiuchi:	Rasalhague
Gamma Orionis:	Bellatrix
Delta Orionis:	Mintaka
Epsilon Orionis:	Alnilam
Zeta Orionis:	Alnitak
Kappa Orionis:	Saiph
Alpha Pegasi:	Markab
Beta Pegasi:	Scheat
Gamma Pegasi:	Algenib
Alpha Phœnicis:	Ankaa
Epsilon Sagittarii:	Kaus Australis
Sigma Sagittarii:	Nunki
Alpha Serpentis:	Unukalhai
Theta Serpentis:	Alya
Beta Tauri:	Alnath
Alpha Trianguli:	Rasalmothallah

Beta Ursæ Majoris:	Merak
Gamma Ursæ Majoris:	Phad (or Phekda)
Epsilon Ursæ Majoris:	Alioth
Eta Ursæ Majoris:	Alkaid (or Benetnasch)
Epsilon Virginis:	Vindemiatrix

The most amusing names are those for Alpha and Beta Delphini: Svalocin and Rotanev. These are strictly modern, and are a reversal of the names of an astronomer, Nicolaus Venator!

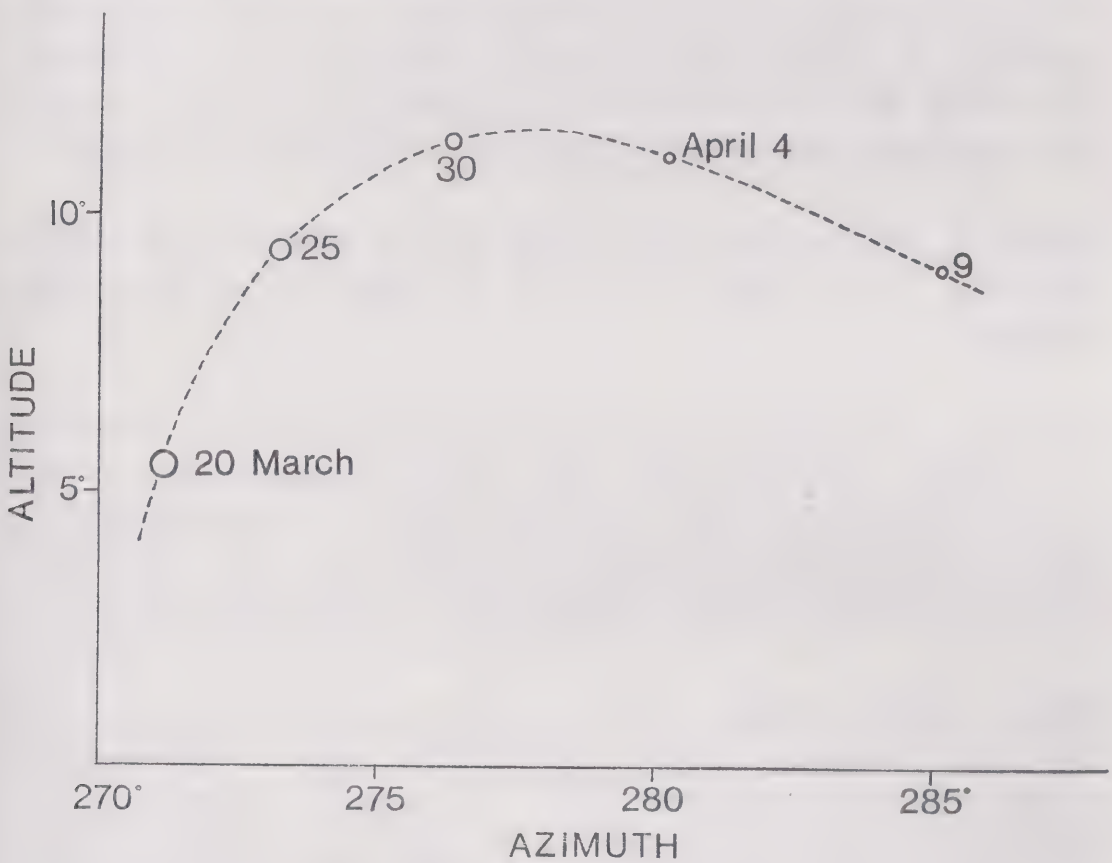
This Month's Lunar Eclipse Only the beginning is visible from Britain. The Sun rises during the eclipse—and since a lunar eclipse can only occur at full moon, and the Sun and Moon must be exactly opposite in the sky (or virtually so), it is obvious that the Moon must then set.

March

Full Moon: 12 March *New Moon*: 26 March

Equinox: 21 March

Mercury is at superior conjunction on 6 March, but then moves rapidly out from the Sun to greatest eastern elongation on 1 April (19°). At the end of March it is very favourably placed as an evening star in the west just after sunset. The diagram shows the changes in altitude and azimuth (true bearing from the north through east, south, and west) of Mercury on successive evenings when the Sun is six degrees below the horizon; this will be about thirty-five minutes after sunset at this time of year. The changes in brightness are roughly indicated by the size of the circles, and it will be seen that Mercury is brightest before the date of elongation.



Mercury

Venus continues to rise at about 5h. each day, but as the Sun rises earlier each day, the period of visibility of Venus diminishes. By the end of the month it rises only about an hour before the Sun, and has then faded to magnitude $-3{\cdot}5$.

Mars continues to rise about three hours before the Sun, and is in the south at sunrise. It moves from Ophiuchus into Sagittarius at the beginning of the month, and forms a fine group with the stars of this constellation. Mars is still a long way from the Earth (about 110 million miles at the end of March) but the distance is closing rapidly and the planet continues to grow brighter (magnitude $+1{\cdot}1$ to $+0{\cdot}6$). Towards the end of the month it reaches its most southerly point, nearly twenty-four degrees south of the equator.

Jupiter is still a morning star, but rises at midnight at the end of March. Its direct motion decreases and it reaches a stationary point on 23 March, some degrees north and west of *Antares*. After this date, the motion is retrograde, but Jupiter returns after opposition, and it will pass closer to *Antares* in October.

Saturn is still a bright evening star, setting north of west before midnight. In this position it will be seen directly below the Pleiades.

Pluto is at opposition on 19 March and its position is shown in the diagram on page 59. It is then actually in the southern part of the constellation Coma Berenices. Pluto is too faint to be seen with small instruments (magnitude about $+14$). The distance at opposition is about 2,830 million miles (4,560 million km.).

Pluto and the Zodiac All the bright planets move in orbits with low inclination to the ecliptic. In the case of Mercury, the angle of inclination is 7°; it is 3° for Venus, and less for the remainder. This also applies to Uranus and Neptune. Pluto, however, is in a class by itself. The angle of inclination is 17°.

and this means that it can leave the Zodiac, as it has now done; when originally found, in 1930, it lay in Gemini.

At present, Pluto is in Coma, and this makes its identification even more difficult, since the area abounds in faint stars. The planet is drawing inward, and at perihelion, in 1989, it will be within the orbit of Neptune, though the higher inclination means that there is no fear of a collision. At its next aphelion, in A.D. 2114, Pluto will be well south of the celestial equator—so far south, indeed, that it will never rise in Britain or the northern United States. The much greater distance will mean, too, that giant telescopes only will be able to show it.

Pluto's unusual orbit has led to the suggestion that it may not be a bona-fide planet, but merely an ex-satellite of Neptune which has moved off in an independent path. There is nothing improbable in this idea, even though we can only speculate as to the way in which the separation took place. The most recent measures indicate that the diameter is about 3,800 miles, which is not very much larger than that of Triton, the senior of Neptune's two present satellites (diameter probably about 3,000 miles, though estimates differ).

Nothing is known about the surface conditions on Pluto, and even the mass is very uncertain. The main problem about its discovery is still unsolved. Lowell calculated its position from its perturbations upon Uranus (not, curiously, upon Neptune, whose orbit was less well known); the predictions proved to be very accurate—and yet if Pluto is smaller than Mars, and is of normal density, it could not exert any measurable effects upon a giant such as Uranus. To suppose that Lowell's success was purely fortuitous does not seem probable, but so far the mystery remains. Neither can we tell whether there is yet another planet beyond Neptune awaiting discovery.

Ophiuchus At the beginning of March, Mars is in Ophiuchus, though it then moves into Sagittarius. Ophiuchus (the Serpent-bearer) intrudes into the Zodiacal region for some distance between Scorpius and Sagittarius, but it is not reckoned as a

Zodiacal constellation. It contains only one bright star (Alpha or Rasalhague, of the second magnitude) and though it covers a wide area of the sky, it is rather deficient in interesting telescopic objects. It separates the two parts of Serpens, Caput (the Head) and Cauda (the Body). In what is evidently meant to depict a life-and-death struggle, Ophiuchus seems to be having the better of matters, since the Serpent has been pulled in half!

An Astronomical Anniversary 10 March is the centenary of the birth of E. M. Antoniadi, a Greek astronomer who spent much of his life in France and carried out important observations with the 33-inch refractor of the Observatory of Meudon. Antoniadi was well known for his keen sight; his map of Mercury, compiled in the 1920s, is probably as good as any more modern chart, and the present-day nomenclature is due to him. He also paid great attention to Mars, and was strongly sceptical of the theory of 'canals', though, surprisingly, he believed that the local obscurations on Mercury were more frequent and prominent than those on Mars (a conclusion which has not been borne out by later research). Antoniadi had close connections with British astronomy, and was for some years Director of the Mars Section of the British Astronomical Association. He remained in France during the German occupation of 1940, and died there before the liberation.

Mars at its Southernmost Northern observers always regret that when Mars is at its closest it is also well south of the celestial equator. This month, as it brightens steadily, it reaches declination −24°, so that Europeans and those in the New York area will find conditions of observation decidedly poor. However, things improve somewhat later, and, when at opposition, Mars will be in Capricornus—still in the south, but well past its lowest.

Sagittarius marks the southernmost part of the Zodiac. It is a rather shapeless constellation, and there is no well-marked pattern, though it contains several stars of the second magnitude.

Rather surprisingly, the stars lettered Alpha and Beta are relatively faint, and lie in the south part of the group; the two brightest stars in Sagittarius are Epsilon and Sigma, so that here, as in other cases, Bayer's alphabetical sequence has not been followed.

April

Full Moon: 10 April *New Moon*: 25 April

Mercury is at greatest eastern elongation on 1 April (19°) and is favourably placed for a few days as an evening star in the west at sunset (see March notes). The planet is in inferior conjunction on 19 April.

Venus is now visible for less than an hour before sunrise, and will remain so for the next few months.

Mars now rises a little earlier (about 2h.) and is growing noticeably brighter (magnitude +0·6 to 0·0). It is moving direct among the stars of Sagittarius, but it is, of course, much brighter than any of these.

Jupiter is now an evening star, rising an hour or two before midnight to the south of east. It is moving retrograde in Scorpius and growing a little brighter (magnitude −1·9 to −2·0) as it approaches opposition. As it is still possible in April to see the planet in a dark sky, this is a suitable opportunity for observing the eclipses and transits of the four great satellites, which are easily seen with a small telescope. Eclipses of these satellites may occur at every revolution, but in 1971, satellite IV (Callisto) passes north or south of the planet and does not undergo eclipse.

Saturn is now approaching conjunction and sets only an hour after the Sun at the end of April. It moves into Taurus during the month, and for the rest of the year its path lies south of the Pleiades.

Uranus is at opposition on 1 April, its position at that time being in Virgo, a little south of the fine double star Gamma Virginis (see diagram on page 59). The distance of Uranus at

opposition is about 1,610 million miles (2,590 million km.) and it will then just be visible to the naked eye (magnitude +5·7). In a telescope it appears as a greenish disk.

Early Discoveries of Variable Stars During April evenings, much of the southern aspect of the sky is taken up with the immense, faint constellation of Hydra (the Watersnake), extending from the boundaries of Cancer as far as those of Centaurus. There is only one bright star, Alphard (Alpha) of the second magnitude. Hydra contains few interesting telescopic objects, but there is one notable variable star. This is R Hydræ, which lies close to Gamma, on the borders of Hydra and Virgo. Like many long-period variables, it is red; at its brightest it is visible with the naked eye, and is an easy object with binoculars for most of its period.

The variability of R Hydræ was discovered in 1704 by the Italian astronomer Maraldi. Previously there were only three known variables; Mira Ceti (first recorded by Fabricius in 1596, but recognized as a variable by Phocylides Holwarda in 1625); Algol (Beta Persei), which is not intrinsically variable, but is an eclipsing binary; and Chi Cygni. It may be of historical interest to list the stars which were known to be variable by the end of the first half of the 19th century; there are some surprising omissions, and some rather surprising inclusions! In chronological order, the discoveries are:

1625	Omicron Ceti (Mira)	Holwarda
1669	Beta Persei (Algol)	Montanari
1686	Chi Cygni	Kirch
1704	R Hydræ	Maraldi
1759	Alpha Herculis	W. Herschel
1782	R Leonis	Koch
1782	Mu Cephei	W. Herschel
1784	Delta Cephei	Goodricke
1784	Beta Lyrœ	Goodricke
1784	Eta Aquilæ	Pigott
1795	R Coronæ Borealis	Pigott
1795	R Scuti	Pigott
1821	Epsilon Aurigæ	Fritsch
1826	R Serpentis	Harding

1827	Eta Argûs (Carinæ)	Burchell
1828	S Serpentis	Harding
1829	R Cancri	Schwerd
1831	U Virginis	Harding
1834	Delta Orionis	J. Herschel
1837	S Virginis	Rogerson
1840	Alpha Orionis (Betelgeux)	J. Herschel
1847	Beta Pegasi	Schmidt
1847	Zeta Geminorum	Schmidt
1848	Lambda Tauri	Baxendell
1848	R Orionis	Hind
1848	R Geminorum	Hind
1848	S Geminorum	Hind
1848	S Hydræ	Hind
1848	R Capricorni	Hind
1848	R Pegasi	Hind
1849	R Tauri	Boguslawsky
1849	T Virginis	Hind
1850	R Piscium	Hind

This list does not include novæ (or the novalike P Cygni). There are several eclipsing binaries, of which Delta Orionis and Epsilon Aurigæ have a small magnitude range; Cepheids are represented by Delta Cephei itself, Eta Aquilæ, and Zeta Geminorum; the remainder are long-period, semi-regular, or irregular stars.

Some naked-eye stars were listed as 'suspected variables' in catalogues of the latter part of the 19th century. These stars included Gamma Pegasi (range $2\frac{1}{2}$–3 : Schwabe), Gamma Eridani ($2\frac{1}{2}$–$3\frac{1}{2}$: Secchi), R Eridani ($5\frac{1}{2}$–6: Gould), S. Eridani ($4\frac{3}{4}$–$5\frac{3}{4}$: Gould), Beta Volantis (4–5: Gould), Epsilon Corvi (3–4: Gould), Delta Ursæ Majoris ($2\frac{1}{2}$–4: Pigott), Gamma Corvi ($2\frac{1}{2}$–3: Gould), Eta Virginis (3–4: Gould), Delta Corvi ($2\frac{3}{4}$–$3\frac{1}{2}$: Gould), Eta Ursæ Majoris ($1\frac{1}{2}$–2: Espin), Beta Ursæ Minoris ($2\frac{1}{4}$–$2\frac{3}{4}$: J. Herschel), Beta Cygni (3–4: Klein), Epsilon Draconis ($3\frac{3}{4}$–$4\frac{3}{4}$: various observers), Epsilon Pegasi (2–$2\frac{1}{2}$: Schwabe) and Eta Pegasi (3–$3\frac{1}{2}$: Christie). Of the stars in this list, only Delta Ursæ Majoris (Megrez, the faintest of the seven stars in the Plough or Dipper) may possibly be truly variable, though any fluctuations can be no more than minor falls below the normal magnitude, and even these are uncertain. In the old catalogues,

Megrez was ranked equal with its companions in the Plough, but it is now a full magnitude fainter, and there is a chance that it has faded since ancient times.

The Galilean Satellites of Jupiter But for the glare of Jupiter itself, all four satellites would be easy naked-eye objects. Large telescopes can show surface details upon them, but it is emphatically not true to say that these details can be seen with telescopes of normal amateur size. Some extravagant claims in this direction have been made, but in fact the features even on Ganymede, the brightest of the Galileans, are difficult to see. The colour of Ganymede is distinctly yellowish. Indications of a tenuous atmosphere have been reported, but as yet there is no proof; the only satellite in the Solar System which is definitely known to have an atmosphere is Titan, the senior member of Saturn's family.

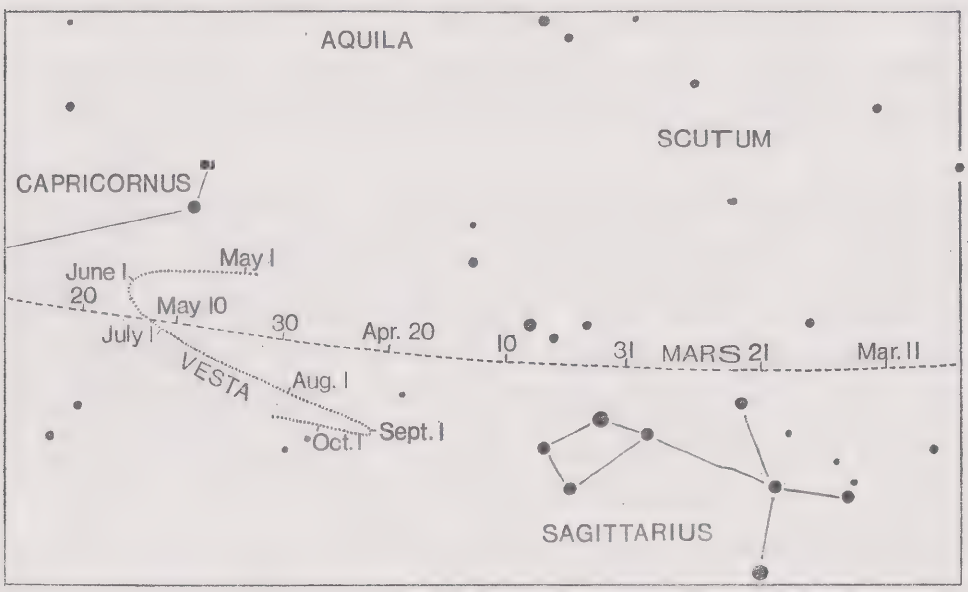
May

Full Moon: 10 May *New Moon*: 24 May

Mercury is at greatest western elongation on 17 May (26°) but the planet will be very low in the south-east at dawn, and is unlikely to be visible.

Venus is still a morning star, but is now very near the Sun and is difficult to see in the bright dawn sky.

Mars now rises about an hour after midnight, a brilliant object (magnitude 0·0 to −0·7) in the south-east. The planet passes into Capricornus at the beginning of the month, and will remain in this constellation for some months to come.



Mars and Vesta

Jupiter is at opposition on 23 May when it will be at a distance of 404,500,000 miles (651 million km.) from the Earth. This is a little nearer than it was in 1970, and it is therefore brighter (magnitude −2·1), though not as bright as Mars will be at

opposition in August. Jupiter is moving retrograde, and passes into Libra in mid-May. It will be quite close to Beta Scorpii for the second time this year on 14 May, and passes less than a degree south of Neptune (also for the second time) on 23 May (see diagram on page 55).

Saturn is in conjunction with the Sun on 17 May and will not be visible during May.

Neptune is at opposition on 23 May when it will be 2,720 million miles from the Earth (4,380 million km.). The path of Neptune is shown in the diagram on page 55). The planet moves very slowly and is in close conjunction with Jupiter on 2 February, 20 May, and 18 September. These conjunctions will enable the planet to be seen in a small telescope as a bluish disk of magnitude +7·7.

Neptune: An Old Controversy Neptune comes to opposition this month. It is an easy binocular object, and a small telescope will show that it is not starlike; it reveals a small, somewhat bluish disk. Its diameter has recently been re-measured, and is now thought to be 31,200 miles, making it slightly larger than Uranus. This is not surprising, since Neptune is appreciably the more massive of the two.

Neptune was discovered in 1846. The story has been told many times, but is worth repeating, because there is an anomaly in the official accounts of the detections of Neptune and of Pluto.

Uranus was discovered by William Herschel in 1781. Subsequently, its orbit was computed, but the predictions were not accurate, and in 1834 an amateur, the Rev. T. J. Hussey, suggested that there might be a more remote planet pulling Uranus out of position. The idea seems to have come to the notice of the then Astronomer Royal, Airy, who paid scant attention to it.

Some years later, two mathematicians independently decided to hunt for the expected planet. Calculations were made in England by John Couch Adams, and in France by Urbain

Le Verrier; the two worked without knowledge of each other's interest, and in fact Adams finished first. He sent his work to Airy, but met with little encouragement, and it was only when Le Verrier, too, completed his calculations, and a memoir on the subject came into Airy's hands, that any action in England was taken. Even then it was somewhat half-hearted. Airy invited Challis, at Cambridge, to search in the indicated position, using the famous Northumberland refractor; also concerned in the hunt was an amateur, William Lassell, who had a finely-equipped private observatory. Most unfortunately, Lassell was rendered *hors de combât* by a sprained ankle; Challis' interest was lukewarm, and there were no accurate star-maps of the region to hand. Challis actually saw the planet, but did not recognize it until Galle and d'Arrest, working at Berlin Observatory on the basis of Le Verrier's calculations, had made the discovery of the world we now call Neptune.

There followed a most acrimonious controversy. The French were furious at claims made on Adams' behalf, and pointed out, quite correctly, that Le Verrier's results had led to the first identification. A compromise was reached, according to which the two mathematicians were afforded equal honour, though it is only honest to say that Adams' part is still largely ignored by French writers. However, nobody has ever suggested that the discoverer was Galle, with his colleague d'Arrest—even though it was they who made the first definite observation with the knowledge that they were looking at a new planet.

So far as Pluto is concerned, the calculations were made by Percival Lowell, of Martian canal fame. Lowell died in 1916; it was only in 1930 that Clyde Tombaugh, working at the Lowell Observatory, located Pluto very close to the position indicated.

Tombaugh is always recognized as being the discoverer of Pluto, though he certainly would not have been searching had it not been for Lowell's mathematical work. On this basis, Galle and d'Arrest should be regarded as the discoverers of Neptune!

However, priorities are basically unimportant; and all those concerned in the discoveries of the outermost planets are entitled to great credit. Whether there will ever be a repetition is uncertain, since any more remote planet is bound to be excessively faint.

Coma South of the Plough lies the constellation of Coma Berenices, or Berenice's Hair. An intriguing old legend is attached to it. It is said that Queen Berenice, wife of a warrior king, vowed to dedicate her beautiful hair to the gods if her husband came back safely from a particularly dangerous war. On his return, she kept her promise, and the gleaming tresses were placed in the sky! Yet Coma is not an ancient constellation in its own right; it was added to the sky by Tycho Brahe during the latter part of the 16th century.

There are no bright stars, but there are many faint ones, and the whole area gives the superficial impression of a large, extended star cluster. This is also the region of the galactic pole, so that interstellar absorption is at its minimum, and many faint external galaxies are visible.

Between Coma and the Great Bear lies another small constellation, Canes Venatici (the Hunting Dogs), formed by Hevelius in 1690. The only bright star is Cor Caroli (Charles' Heart), of the third magnitude. Hevelius was responsible for forming eleven new constellations; of these, Camelopardus, Canes Venatici, Vulpecula, Lacerta, Leo Minor, Lynx, Scutum, Monoceros, and Sextans are still to be found in modern maps, while the remaining two (Cerberus and Triangulum Minor) are not.

June

Full Moon: 9 June *New Moon*: 22 June

Solstice: 22 June

Mercury is in superior conjunction on 21 June, and will not be visible.

Venus continues to rise less than an hour before the Sun to the north of east. The planet passes less than a degree north of Saturn on 11 June, but this conjunction will be difficult to see in the bright dawn sky.

Mars rises in the south-east at midnight at the beginning of June, and although the summer skies are never really dark at this hour, the brilliance of the planet makes it quite unmistakable. Its distance from the Earth is rapidly decreasing (from 63 million to 46 million miles during the month) and as a result its brightness increases by a whole magnitude −0·7 to −1·7). The planet is still moving to the west of Capricornus.

Jupiter is a brilliant object in the evening sky, but now sets before sunrise. It is still moving retrograde in Libra, and is a little less bright than it was at opposition (magnitude −2·1 to −2·0).

Saturn is now a morning star, rising nearly two hours before the Sun at the end of June. It is moving direct in Taurus, and will be found about six degrees south of the Pleiades, its magnitude being +0·4.

Midsummer Ceremonies The summer solstice occurs on 22 June, and ceremonies to mark midsummer are held in many countries of the northern hemisphere. One of the most famous of these is at Stonehenge, the ancient stone circle in Wiltshire (England). The Stonehenge monument is popularly associated

with the Druids, and the Druidical ceremonies held there each Midsummer Day are well known.

Yet picturesque though the ceremonies may be, it is unfortunately true that there is no connection whatsoever between Stonehenge and the ancient Druids! Stonehenge was constructed by the Beaker People, and was complete by 1300 B.C.; the Druid cult did not reach England until a thousand years later. In fact, the Druids are as remote in time from Stonehenge as we are from William the Conqueror. There is no evidence that the ancient Druids took any interest in the stone circle, and there is a great deal of evidence that they did not. Massive monuments were not of their making; they had their sacred groves. Also, Druid learning was passed on almost entirely by word of mouth, which is why our knowledge of it is so scanty.

According to Professor Gerald Hawkins, Stonehenge was built as a primitive eclipse computer; and he has marshalled impressive evidence to support his theory. Certainly it has an astronomical connection, though full details of its original rôle will probably never be known now.

Nova Serpentis, 1970 On 15 February 1970, the Japanese amateur, A. Honda, discovered a fifth-magnitude nova in the constellation of Serpens. It increased to magnitude $4\frac{3}{4}$ before starting to fade, and was at one time easily visible with the naked eye. It was thus the third naked-eye nova in four years, the others being Nova HR Delphini (1967) and Nova Vulpeculœ (1968), both discovered by G. E. D. Alcock.

During recent years, the Japanese amateurs have made great efforts in hunting down comets and novæ. Their successes have been regular, particularly with regard to comets; Seki, Sato, Kosaka, Tago, and Honda himself have all made discoveries. Of these, only Honda is aged over twenty-one. Certainly the Japanese show immense skill and dedication; elsewhere, only L. G. Peltier in America and Alcock in England can be ranked equal with them. No doubt they will have many more successes in the future.

The recent novæ have not been alike. HR Delphini stayed near maximum brightness (around magnitude 4) for months, and in early 1970 it was still only slightly below magnitude 8; it is undoubtedly the slowest nova on record. Its pre-outburst magnitude was 12, so that it is never likely to become too faint to be followed with moderate telescopes. Nova Vulpeculæ was much more conventional; it faded below naked-eye visibility in a week or so, and by 1970 it had dropped to below magnitude 13.

Nova Serpentis was identified on pre-discovery photographs, showing that the rise was fairly quick (the magnitude on 14 November was 6·8). So far as can be ascertained, the pre-outburst magnitude was no brighter than 17, so that it may be expected to resemble Nova Vulpeculæ rather than the exceptional HR Delphini. Its position is: R.A. 18h 28m·2, declination +02°40′. Shortly after this discovery, Honda found a second, fainter, nova in Aquila.

Observing ex-novæ is a favourite pastime of some observers who are equipped with powerful telescopes. Some are of special interest; for instance, DQ Herculis, the 1934 nova discovered by J. P. M. Prentice, is now an eclipsing binary of short period. At its maximum it exceeded the second magnitude, and remained visible to the naked eye until the spring of 1935, after which it suffered a sudden decline. The southern nova of 1925, RR Pictoris, is also a faint eclipsing binary.

A Planetary Conjunction Observers who have adequate telescopes will be able to see the conjunction of Venus and Saturn on 11 June. This will be an interesting moment to compare the surface brightnesses of the two planets. Venus has a much higher albedo, and Saturn will appear relatively dull and lustreless by comparison. The conjunction is quite a close one, but the occultation of one planet by another is a surprisingly rare event.

Though Venus is badly placed for observation at the moment, it is still much brighter than any other star or planet—partly

because of its great reflecting power, and partly because it is the closest natural body in the sky apart from the Moon.

Scorpius The brilliant Zodiacal constellation of the Scorpion is now at its best in the evening sky. Antares rises to a reasonable height above the European horizon, but the 'Scorpion's sting', with the bright star Shaula (Lambda Scorpii), is much further south. It is interesting to 'follow down' the line of stars in the constellation and see the southernmost limits of visibility.

July

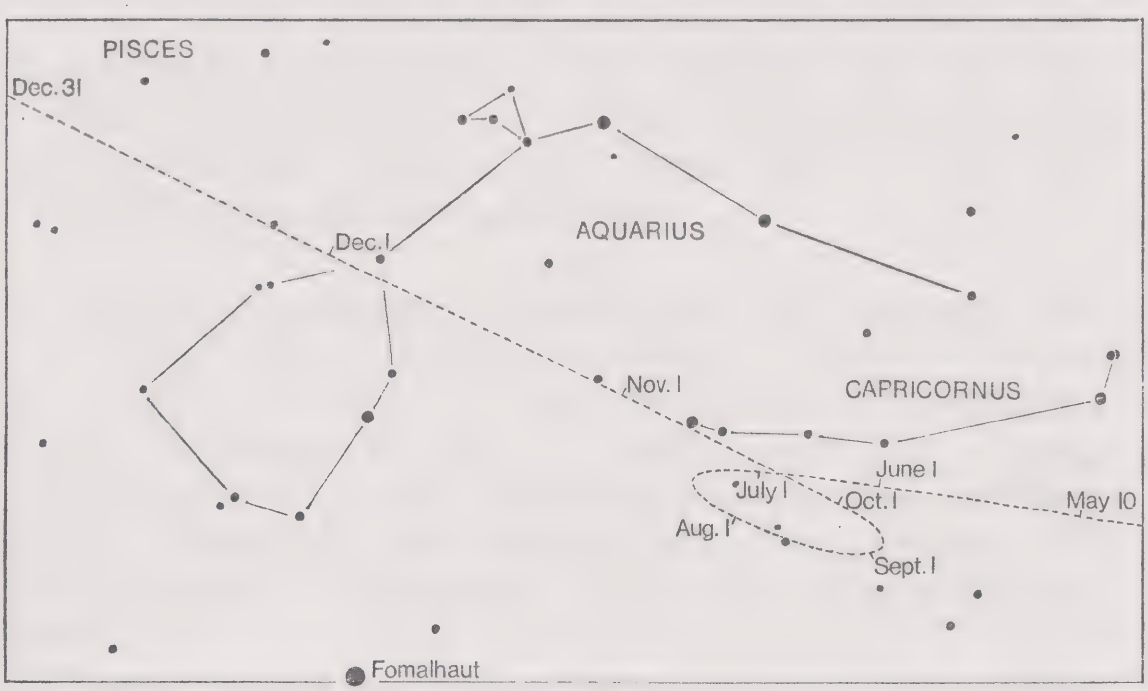
Full Moon: 8 July *New Moon*: 22 July

Earth is at aphelion (farthest from the Sun) on 4 July, when its distance will be 94,500,000 miles (152,100.000 km.).

Mercury is at greatest eastern elongation on 29 July (27°), but it is not very bright and will be lost in the twilight in the western sky at sunset.

Venus is now moving in towards superior conjunction, and is not likely to be seen after mid-July.

Mars reaches a stationary point on 13 July at the eastern end of Capricornus and then begins to move in the retrograde direction. The loop in its path (see diagram on page 72) is quite small this year, and covers an angle of about ten degrees in sixty days. The planet rises before midnight, and by the end of the month will be seen in the late evening as the brighest star in the sky.



Mars—May to December

Jupiter also reaches a stationary point on 25 July after which it moves direct again through Libra. The planet will be seen in the south at sunset (magnitude $-2{\cdot}0$ to $-1{\cdot}9$) and sets at midnight in mid-July.

Saturn rises at midnight at the end of July, when it will be found to the north of east between *Aldebaran* and the Pleiades. It makes a fine group with these stars of Taurus, and it will be interesting to compare its magnitude ($+0{\cdot}4$) and colour with those of *Aldebaran* (magnitude $+1{\cdot}1$).

A partial eclipse of the Sun on 22 July will be visible only in Alaska and north-east Asia.

Vesta will be at opposition on 22 July, when it reaches magnitude $+5{\cdot}7$, and should then be visible to the naked eye (see notes on page 107. The path of Vesta at this time is shown in the diagram on page 80.

Retrograding of Planets During part of July, Mars seems to move in an east-to-west or retrograde direction against the starry background, so performing a 'loop'. Jupiter has been retrograding, but after 25 July it again resumes its direct or west-to-east motion.

The fact that the planets do not move uniformly against the stars has been known since very early times, and it was in fact one of the great stumbling-blocks in the way of the old Ptolemaic theory, according to which the Earth lies in the centre of the universe, and the orbits of all celestial bodies must be true circles (because the circle is the perfect form, and nothing short of perfection can be tolerated in the heavens!). Ptolemy of Alexandria, who brought this system to its greatest development (A.D.120–180), was forced to introduce cumbersome systems of large and small circles. Yet the true explanation of retrograding is quite simple.

A superior planet, such as Mars or Jupiter, has an orbital velocity less than that of the Earth, and is moving in a larger

path. Therefore, some time to either side of opposition, the Earth will be 'by-passing' the planet; and the effect of this is to produce apparent retrograding—it does not, needless to say, indicate any real change in the motion of the planet. Before and after retrograding, the planet will reach a stationary point. This month, Mars reaches this point on 13 July, prior to retrograding (before opposition); Jupiter does so on 25 July, after retrograding (after opposition). The inferior planets Mercury and Venus, which lie within the Earth's orbit, behave in a superficially different manner, but they also can move in a retrograde direction.

The Perseids The first meteors of the annual Perseid shower will be seen toward the end of July. Unfortunately the conditions this year will not be favourable, since the Moon will be very much in evidence except when the shower is on the wane in the mid-part of August. However, some of the Perseid meteors are so bright that they should be visible even under moonlight conditions.

The Globular Cluster in Hercules The large, rather dim constellations of Hercules, Ophiuchus, and Serpens are now well placed in the evening sky. Hercules is notable mainly because it contains Messier 13, the finest globular cluster visible from Europe or the United States. There are only two brighter globulars in the whole sky; these are Omega Centauri and 47 Tucanæ, in the far south.

M.13 is just visible to the naked eye on a clear night. It lies between Zeta and Eta Herculis, rather closer to Eta; binoculars show it clearly, and in a moderate telescope it is a fine sight. Like all globulars, it is symmetrical, and is wholly resolvable. There is a fundamental difference between a globular and an open or loose cluster such as the Hyades or the Pleiades; the open clusters are probably impermanent by galactic standards, and will be dissipated by gravitational forces, whereas the globulars are relatively stable systems.

It has been said that globular clusters form a sort of outer framework to the Galaxy, and they do indeed make up part of the galactic halo; they consist of Population II, so that the brightest stars are old red giants which have long since left the Main Sequence. They contain many RR Lyræ variables, which have very short periods and which are of approximately uniform luminosity (around ninety times brighter than the Sun), so that they can be used as 'standard candles' in the same way as the Cepheid variables. M.13 itself is rather unusually poor in RR Lyræ stars, but some have been found. The size of the Galaxy was first measured by Shapley, who studied the RR Lyræ variables in the globular clusters and drew up the first reliable picture of the overall system.

Even in the centre of a globular cluster, the individual stars are still widely separated, and direct stellar collisions must be exceedingly rare. However, an astronomer living on a planet moving round a star within M.13 would see a glorious night sky; there would be many stars shining more brilliantly than Venus does to us, and there could be no proper 'darkness'. This would have its disadvantages, since investigations of conditions outside the cluster would be considerably hampered. From a purely astronomical point of view, it is just as well that we live in a less populated part of the Galaxy.

The other really interesting object in Hercules is Alpha (Rasalgethi), a huge red giant of spectral type M; it has a fainter companion which appears decidedly green. Rasalgethi is variable between magnitudes 3 and 4. It lies close to the brighter Alpha Ophiuchi (Rasalhague) of magnitude 2.

August

Full Moon: 6 August *New Moon*: 20 August

Mercury is in inferior conjunction on 26 August, and will not be visible during August.

Venus is in superior conjunction on 27 August. After this date it becomes an evening star, but it moves very slowly out from the Sun and it will be another three months before it is clearly visible in the western sky at sunset.

Mars is at opposition on 10 August and is nearest to the Earth on 12 August (35 million miles, 56 million km.). It is nearly at perihelion (see September notes) and is closer to the Sun and Earth than it has been at any time since 1956. It reaches magnitude $-2{\cdot}6$ at opposition—brighter than any other planet except Venus. Another effect of the nearness of Mars is that its parallax is much greater, and its apparent position is well south (about six degrees) of the ecliptic. At these favourable oppositions of Mars, the south pole of the planet is exposed to view.

Jupiter sets before midnight and is moving direct on the borders of Libra and Scorpius. Although still a brilliant object, it is fading (magnitude $-1{\cdot}9$ to $-1{\cdot}7$) as its distance increases. Jupiter may be seen some degrees north of the Moon on 1 and 28 August, the Moon being then at about First Quarter.

Saturn now rises north of east before midnight. It begins to grow a little brighter (magnitude $+0{\cdot}4$ to $+0{\cdot}3$) and will be seen just north of the Hyades, almost on a line joining *Aldebaran* and the Pleiades.

A total eclipse of the Moon occurs on 6 August. In the British Isles, the Moon will rise totally eclipsed and the shadow of the

Earth will pass completely off the face of the Moon about fifty minutes later (see notes on page 103).

A partial eclipse of the Sun on 20–21 August is visible only in Australasia and the Antarctic.

The 'Seas' of Mars The first useful map of Mars was drawn up in 1840 by the German observers Beer and Mädler, best known for their work in connection with the Moon. Bright and dark areas were shown, together with indications of the features which later came to be known as canals. During the 1870s, better charts were produced, and the modern nomenclature was introduced in 1877 by G. V. Schiaparelli.

Originally it had been thought that the dark areas were seas, while the light patches were land. There seemed no reason to doubt that Mars had a dense atmosphere, and that life flourished there. Then, gradually, opinions changed; it became clear that the Martian atmosphere is tenuous, and that there can be little water on the surface of the planet. In 1878, E. Liais made the suggestion that the dark patches were likely to be tracts of vegetation, and this theory was generally supported until very recently. Even now it has not been disproved, though it is starting to look as though Mars may be lifeless.

The dark areas are essentially permanent, though there are minor alterations in outline. Some of them, such as the Syrtis Major in the southern hemisphere and the Mare Acidalium in the north, are visible with small telescopes when Mars is near opposition. This month the southern pole is presented, and Syrtis Major will be a conspicuous feature. It was first drawn in recognizable form by C. Huygens in 1659, and there is no reason to suppose that it has altered since then—or, indeed, for many millions of years.

It was natural to assume that the dark areas were low-lying, and measures indicate that they are slightly warmer than the ochre 'deserts', so that until the Mariner flights of the 1960s the idea of lowly vegetation growing inside a depressed basin had

much to recommend it. It was thought that the atmosphere must be composed chiefly of nitrogen, with a ground pressure of the order of eighty-five millibars (roughly equal to the pressure in our own atmosphere at 52,000 feet above sea-level). However, the Mariner results of 1965 and 1969 have caused a complete change in outlook. The atmosphere has a ground pressure of only about six millibars (less than that at 100,000 feet above sea-level on Earth), and the main constituent is carbon dioxide. The white polar caps, formerly attributed to ordinary ice or frost, are likely to be solid carbon dioxide, and the chances of life existing on Mars are greatly reduced. Part of the surface is cratered, while there are some ‘chaotic’ regions, and one feature—the circular plain Hellas—seems to be virtually blank.

Suggestions were made that instead of being depressions, the dark areas might be elevations. If this were so, the seasonal changes could be attributed to shifting dust, while the famous ‘canals’, some of which have a basis of reality, could be due to mountain chains or to aligned craters. More recently still, some ingenious experiments carried out by Wells seem to show that there is no correlation between elevation and colour; some of the Martian dark areas are low-lying, while others are mountainous. Wells’ method was to measure the pressure of the carbon dioxide over various regions; it is logical to assume that the pressure will be less over elevations, just as on Earth the pressure on a mountain-top is less than that over the country below.

If Wells’ results prove to be accurate (and there is no reason to question them), we must find some new explanation for the dark areas on Mars. Vegetation now appears improbable, even though it cannot yet be ruled out; it is not easy to see how dust can be responsible, in view of the seasonal cycle in which what de Vaucouleurs has called ‘a wave of darkening’ spreads from the pole towards the equator when the polar cap shrinks. It may be that the darkness is due to nothing more than a difference in the surface texture, but here too there are objections, and we must confess that at present the Mariner results have increased our uncertainties about Mars rather than solving them.

The American space-programme is in a state of some flux, and it is possible that financial considerations will slow down the plans for the further exploration of Mars. However, it is likely that Martian Orbiter probes will be dispatched within the next few years, and if all goes well there should be a soft landing by an automatic vehicle before 1975. Then, perhaps, we shall be able to solve the mystery of the Martian 'seas'.

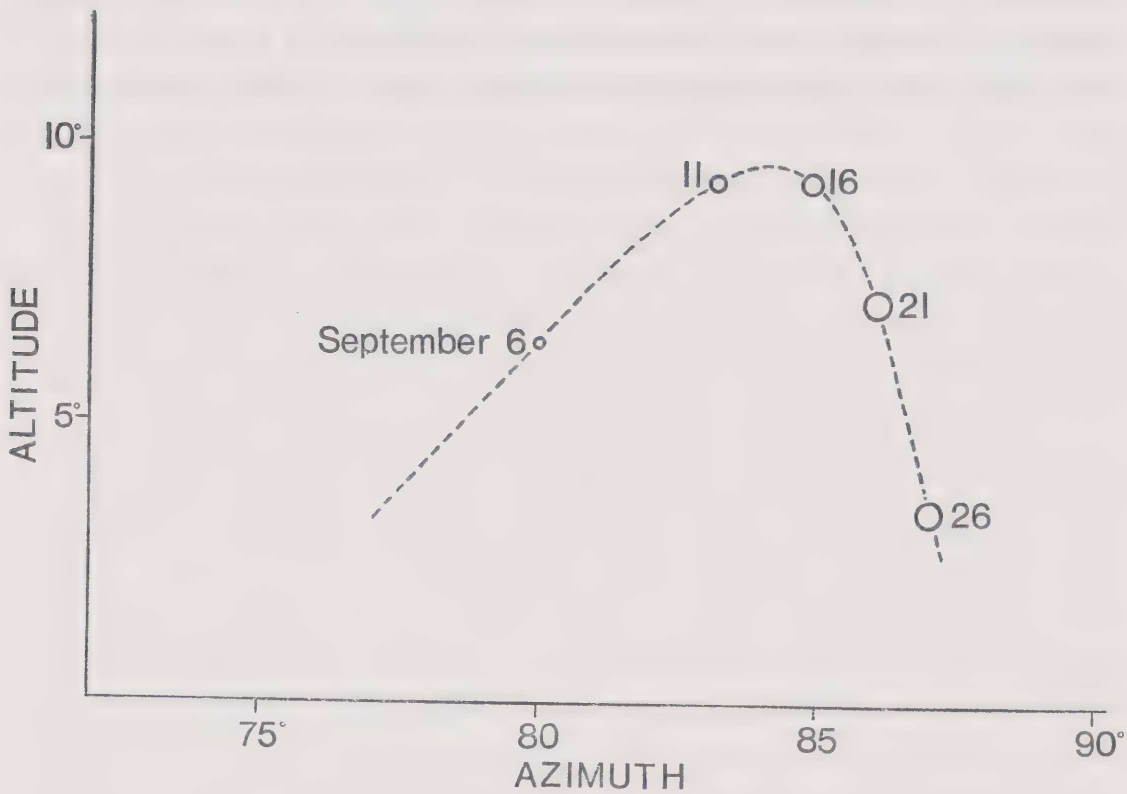
Finally, it is worth noting that even after 1969 Mariners had by-passed Mars and sent back their results, their work was still not finished. Contact with them was maintained, and on 7 March 1970, Mariner 6 was used in an experiment in connection with the total solar eclipse of that day. The probe was then on the far side of the Sun, at 235,000,000 miles from Earth, and signals from it were picked up, providing information about the effects of the eclipse upon the Earth's ionosphere. Mariner 7 reached a comparable point a month later. There can be no doubt that these two probes ranked among the greatest of all the American achievements in the first years of the Space Age.

September

Full Moon: 5 September *New Moon:* 19 September

Equinox: 23 September

Mercury comes to greatest western elongation on 12 September (18°) and this is a favourable opportunity to see the planet as a morning star in the east at sunrise. The diagram shows the changes in altitude and azimuth of Mercury on successive mornings when the Sun is six degrees below the horizon—this is about thirty-five minutes before sunrise at this season. The changes in brightness are roughly indicated by the size of the circles, which show that Mercury is much brighter after the date of western elongation.



Venus is now theoretically an evening star, but is still too close to the Sun to be seen with the naked eye.

Mars is still a brilliant evening star, setting in the south-west in the early morning hours. It reaches a stationary point on 11 September in the centre of the constellation Capricornus, and then begins to move direct again. The planet is at perihelion on 8 September, when its distance from the Sun is 128 million miles, but its distance from the Earth is now rapidly increasing, and as a result it fades from magnitude $-2{\cdot}3$ to $-1{\cdot}5$ during the month.

Jupiter sets in the evening in the south-west, but for the next month or two it is only likely to be seen in the twilight sky. Jupiter is less brilliant than Mars at the beginning of September, but by the end of the month, Mars will have faded appreciably and the planets are then of about the same magnitude $-(1{\cdot}5)$. Jupiter is in conjunction (about one degree south) with Neptune for the third time on 18 September, and at the end of the month the planet Jupiter moves into Scorpius and will again be close to Beta Scorpii (about $\frac{1}{2}°$ south).

Saturn rises in mid-evening in Taurus, just north of the Hyades and *Aldebaran*. Even in this region of the sky, the planet is much the brightest object (magnitude $+0{\cdot}3$ to $+0{\cdot}2$). It reaches a stationary point on 19 September, and will be moving retrograde after this for the rest of the year.

Mariner to Mercury Mercury's surface features have never been well mapped, because the planet is so difficult to observe; probably the chart drawn by Antoniadi over forty years ago remains the best. Plans have now been announced for a Mercury probe in 1972. It will by-pass Venus, and the gravitational field of Venus will be used to swing the probe inward toward Mercury—a variant of the 'Grand Tour' idea which has become so widely discussed. Whether the probe will carry television equipment is not yet known, but it is logical to assume that every effort will be made to obtain close-range pictures. Probably Mercury, like the Moon and Mars, will prove to be cratered.

The Great Spiral in Andromeda One of the most famous objects in the sky, the Great Spiral, is excellently placed for observation this month. It lies fairly near the fourth-magnitude star Nu Andromedæ, and is visible to the naked eye as a misty patch. It was first described definitely by Mayer in the early 17th century; curiously, Tycho Brahe, who drew up the best star-catalogue of pre-telescopic times, made no mention of it.

In a small telescope the Spiral is frankly disappointing, and looks like nothing more than a dim, misty patch. Even in larger instruments it is not spectacular, and long-exposure photographs taken with powerful telescopes are needed to show its structure. It is almost edge-on to us (the angle of sight is about 15°), and therefore the spiral form is not so well displayed as with other galaxies such as the Whirlpool, M.51 in Ursa Major.

Originally it was thought that the Spiral, and others of its kind, must belong to our Galaxy. Messier's catalogue, in which the Spiral is numbered 31, contains a grand medley of nebulæ, open clusters, globulars, and the objects that we now know to be external systems. The problem was solved only in 1923, when E. E. Hubble located Cepheid variables in the Spiral. These Cepheids act as standard candles; their periods of variation are linked with their real luminosities, and therefore their distances can be calculated as soon as their light-variations have been plotted. Hubble found that the Cepheids were much too remote to belong to our Galaxy, and it followed that M.31 itself must be external. The distance was estimated as 900,000 light-years. However, a revision of the Cepheid scale, carried out by W. Baade in 1952, proved that the real distance must be greater. The modern value is 2,200,000 light-years, and the Spiral is considerably larger than our own.

M.31 contains objects of all kinds: stars, clusters, nebulæ, and interstellar matter. There have been many novæ seen in it, as well as one supernova, the famous S Andromedæ of 1885, which attained the sixth magnitude. Two smaller companion galaxies exist, M.32 and N.G.C. 205, both of which are elliptical.

It is often said that all the galaxies are receding from us,

but this is not strictly true. M.31 belongs to what is called the Local Group, which consists of more than two dozen systems; the most important are M.31, our Galaxy, the Triangulum Spiral (M.33), and the two Clouds of Magellan, which are too far south to be seen from Britain or the United States. The Local Group forms a stable unit, and the galaxies in it are not receding from each other; at present M.31 is actually approaching us, though this is due to the motion of the Sun round the centre of our Galaxy, and the approach will not continue indefinitely. To be accurate, then, we must say that every group of galaxies is receding from every other group.

The Triangulum Spiral is smaller than M.31, and is rather further away (2,350,000 light-years). It is rather faint, and is best seen with very low powers. It, too. is well placed for observation this month.

Capella and Vega During evenings in September, Capella and Vega are at about equal altitude; they lie on opposite sides of the pole. Their magnitudes are almost exactly equal (0·05 and 0·04 respectively), but they are not alike. Capella is a yellow giant of spectral type G, so that its surface temperature is equal to that of the Sun; Vega is a blue Main Sequence star of type A. Capella is 150 times as luminous as the Sun, while Vega is the equal of fifty Suns. In the northern hemisphere of the sky, there is only one star which is brighter; this is Arcturus (magnitude −0·06), which is below the horizon during evenings this month.

October

Full Moon: 4 October *New Moon:* 19 October

Mercury is in superior conjunction on 8 October and will not be visible during the month.

Venus is an evening star, but is moving out very slowly from the Sun. At the end of the month it sets in the south-west about half an hour after the Sun.

Mars continues to set about midnight in the south-west. At the end of October it moves from Capricornus into Aquarius, and although it will have faded to magnitude −0·7, it is still the brighest object in this part of the sky.

Jupiter is an evening star, setting in the south-west in the early evening. It moves from Scorpius into Ophiuchus at the end of the month, and on 30 October it will be seen about five degrees north of *Antares*. It forms a fine group with the stars of Scorpius, but is much brighter than any of these (magnitude −1·4).

Saturn is approaching opposition, and now rises about two hours after sunset. It continues its retrograde motion in Taurus and is growing brighter (magnitude +0·2 to 0·0). The rings are now quite widely open, and the planet is a fine object for a small telescope, which will also show Saturn's largest satellite, Titan.

The October Meteors Though the August Perseids are more reliable and prolific than any other annual showers of meteors, there are two showers in October which are worthy of attention. These are the Taurids and the Orionids. Their periods of activity overlap; officially the Orionids end on 25 October, while the Taurids begin one day earlier.

Neither shower is really rich. The zenithal hourly rate (Z.H.R.) of the Orionids is twenty, that of the Taurids only six, though these figures are only approximate, and change somewhat from year to year. The Z.H.R. is the number of meteors which would

be expected to be seen by an observer to whom the radiant is exactly overhead, under ideal conditions. In practice the radiant is practically never overhead, and ideal conditions are never attained, so that the number of meteors actually observed per hour is always appreciably less than the theoretical Z.H.R.

Formerly, all important work on meteors was carried out by visual observers; the paths were plotted, and the frequencies noted, together with the magnitudes, colours, and other characteristics of the individual meteors. This is not the case today, when radar methods have largely taken over, but amateurs of the past laid the essential foundations, and the work of observers such as W. F. Denning will always be remembered. The modern meteor observer tends to concentrate upon obtaining spectra, which naturally means a great deal of effort; since one can never tell when or where a meteor will appear, spectra are hard to obtain. However, some amateurs, notably H. B. Ridley in England, have achieved important successes in this field.

Mira Ceti The large, rather faint constellation of Cetus is on view during October evenings. Its brightest star, Beta Ceti or Diphda, is of the second magnitude, and lies well below the Square of Pegasus; it is sometimes confused with Fomalhaut in Piscis Austrinus (the Southern Fish), but the two are easy to distinguish, since Fomalhaut is further west, is lower in the sky, and is a magnitude brighter.

Cetus is notable mainly because it contains the famous variable Mira (Omicron Ceti). The period is 331 days, though, as with all long-period stars, no two cycles are exactly alike. In 1969 the magnitude reached 2 in August—brighter than at any time during the past half-century. In 1970, maximum occurred in July, and this year it took place in June, when the star was too near the Sun to be observable. By October, Mira will have faded below naked-eye visibility, but it never drops below the 10th magnitude, and can always be located with the help of a small telescope. It is a red giant of spectral type M, and has a 9th-magnitude white companion.

The Wandering Pole The Great Bear, Ursa Major, is probably the best-known of all the constellations, though its stars are not so bright as those of Orion or the Southern Cross. Over Britain and the northern United States it never sets, and two of its stars point to Polaris in Ursa Minor, which lies within one degree of the north celestial pole.

Polaris makes an excellent pole star, but it will not retain its place indefinitely. In the period of Egyptian greatness, when the Pyramids were built, the pole star was the much fainter Thuban, in the constellation of Draco (the Dragon); in 12,000 years from now, the pole will lie not far from the brilliant Vega. In fact, the pole seems to wander, because of the phenomenon of precession. The Earth is behaving rather like a top which is running down, and is starting to topple; the polar point describes a 47° circle in the sky, taking about 24,000 years to complete one journey. There is no mystery about precession. It is due to the pull of the Sun and Moon on the Earth's slight but significant equatorial bulge.

Precession was discovered by the Greek astronomer Hipparchus, and has been closely studied ever since. All star maps have to be drawn to some definite 'epoch', because over periods of a few decades the shift in the pole's position has a marked effect upon the right ascensions and declinations of the stars.

There is no bright south polar star. The nearest naked-eye object is Sigma Octantis, which is only of the fifth magnitude. In fact, the south celestial pole lies in a decidedly blank area, but it can be located easily by using two of the stars in the small but very bright constellation of Crux Australis, the Southern Cross, which is as familiar to Australians and New Zealanders as is the Great Bear to Britons and New Yorkers.

November

Full Moon: 2 November *New Moon:* 18 November

Mercury is at greatest eastern elongation on 23 November (22°), but is rather badly placed, very low in the south-west just after sunset. It should not be confused with Venus, which is very much brighter, and in the same part of the sky.

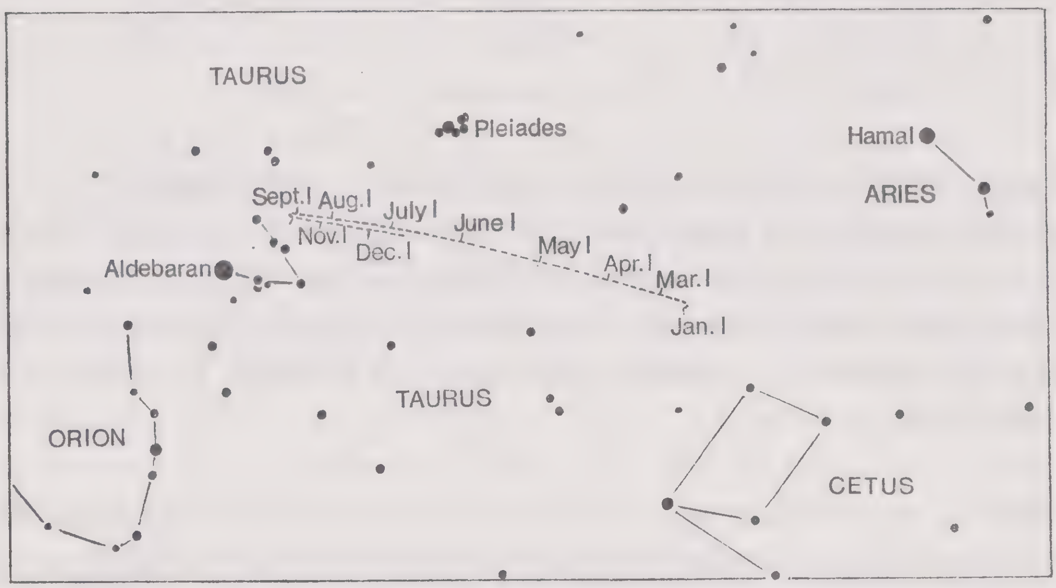
Venus now begins to appear as an evening star, and by the end of the month sets more than an hour after the Sun, low in the south-west. Venus passes four degrees north of *Antares* on 12 November, and about one degree south of Jupiter on 14 November, but these two conjunctions may be difficult to observe in the twilight.

Mars is an evening star, moving direct through Aquarius. Its motion brings it farther north, and one result of this is to cause the planet to set about the same time each night (midnight). The brightness of the planet continues to decrease (magnitude −0·7 to 0·0) as its distance rapidly increases; it is already twice as far from the Earth as it was at opposition. In the early evening hours, Mars will be seen in the south, below the right-hand side of the Great Square of Pegasus. Below it and low down near the horizon is the bright star *Fomalhaut*, which is thirty degrees south of the equator.

Jupiter is now setting low in the south-west shortly after sunset. The conjunction with Venus is mentioned in the notes given above, and it will be interesting to look for these two bright planets before the sky becomes completely dark (magnitudes: Jupiter −1·4, Venus −3·3).

Saturn is at opposition on 25 November, and is very favourably placed for observation. Although the rings are not yet open to

their greatest extent, they add a great deal to the brightness of the planet, and its magnitude reaches $-0{\cdot}2$. It will be high in the sky at midnight among the stars of Taurus. The distance of the planet at opposition is about 752 million miles (1,210 million km.).



Saturn, 1970

The Composition of Saturn's Rings So far as we know, Saturn is unique. There is certainly nothing else like it in the Solar System, and for beauty Saturn is unrivalled. The ring-system was first correctly described by C. Huygens in the 17th century, but for a long time the nature of the rings themselves remained uncertain. Mathematical investigations by Clerk Maxwell showed that the rings could not be solid or liquid sheets, since they lie entirely within the Roche limit for Saturn, and a ring of this nature would be quickly disrupted. Instead, Maxwell suggested that the rings could be made up of swarms of small particles, moving round the planet in independent orbits. This was confirmed spectroscopically by J. E. Keeler, who showed that the ring particles closest to the planet move more quickly than those in the outer parts of the system.

The rings are highly reflective (their albedo is much higher than that of the globe), and it followed that they might be made up of icy or ice-coated material. Investigations carried out by G. P. Kuiper in 1969 indicate that the particles are likely to be composed of ammonia ice rather than ordinary water ice, and this is now regarded as the most probable explanation.

The Cassini Division, which separates the two bright rings, is due to the gravitational effects of Saturn's inner satellites, which keep the Cassini region 'swept clear' of particles. The various minor divisions reported from time to time are also due to satellite perturbations. A dusky ring (D) outside the main system was reported by G. Fournier in 1909, and various other accounts of it have been given, but its existence has never been confirmed, and its reality is doubtful.

The rings are very thin (less than ten miles thick), and were last edge-on to the Earth in 1966. In 1971 they are still opening out, and cover up much of the planet's northern hemisphere. Saturn is therefore at its most spectacular, and a small telescope will show the ring system, though more powerful instruments are needed to examine it in detail. The planet is now brighter than any of the stars apart from Sirius and Canopus.

The Leonids The Leonid meteor shower can provide brilliant displays, as happened in 1833, 1866, and 1966. The period is $33\frac{1}{3}$ years, and so it is not expected that there will be a major display in 1971, but it will be worth keeping a watch during the early morning of 17 November. Conditions are favourable inasmuch as there will be no moon.

Biela's Comet One of the most famous comets in astronomical history is Biela's, which used to have a period of $6\frac{3}{4}$ years. It was seen in 1826 and again in 1832, when it was a bright telescopic object. It was missed in 1839, because it was unfavourably placed, but returned again in 1845, when it caused a sensation by splitting into two parts. The 'twins' came back once more in 1852, by which time they had separated con-

siderably. They were missed again in 1859, as they were badly placed, but were confidently expected in 1865. To the surprise of all astronomers, they failed to put in an appearance. They were again absent at the next return, that of 1872, but in their place appeared a bright meteor shower, radiating from the constellation of Andromeda. There seems no doubt that these meteors represented the débris of the dead comet, and displays were also seen in subsequent years between 26 November and 4 December. By now the shower has become very weak, but a few Bieliid or Andromedid meteors are still seen annually, and meteor observers will be on the watch for them in 1971, though the Moon will be full on 2 December.

Aries In the list of Zodiacal constellations, Aries (the Ram) occupies first place—though precession has now shifted the vernal equinox into the adjacent constellation of Pisces, so that, strictly speaking, Aries should be ranked as the last constellation in the Zodiacal belt.

It is not a large or brilliant constellation, but it is easy enough to identify, since its three main stars make up a distinctive group between Andromeda and Cetus. The brightest star, Alpha Arietis (Hamal) is of the second magnitude; Beta is of the third. The most interesting of the three is, however, Gamma Arietis, which is a wide, easy double. Both components are of the fourth magnitude, and they are to all intents and purposes identical twins. A small telescope will separate them easily, and this is one of the best of all doubles for observation with low powers. Also in the constellation is the long-period variable R Arietis, which ranges between magnitude $7\frac{1}{2}$ and 13. It has a period of 187 days, and, like so many of its kind, is a very remote red giant star.

December

Full Moon: 2 and 31 December *New Moon:* 17 December

Solstice: 22 December

Mercury is in inferior conjunction on 12 December, and will not be visible during December.

Venus is now an evening star, and by the end of the year it sets in the south-west more than two hours after the Sun. Venus will be a brilliant evening star throughout the Spring months of 1972.

Mars is still an evening star, setting at midnight in the south-west. It moves from Aquarius into Pisces in mid-December and at the end of the year will be seen under the left-hand side of the Great Square of Pegasus. By then it will have faded to magnitude of +0·5, but is still much brighter than the other stars in this part of the sky. There is no opposition of Mars in 1972, the next such event occurring in October 1973.

Jupiter is in conjunction with the Sun on 10 December, and will not be visible until the end of the month, when it rises in the south-east about an hour before the Sun. Early in 1972 the planet moves into Sagittarius, and will be at opposition in that constellation in June.

Saturn remains a bright evening star, but is now fading a little (magnitude −0·2 to 0·0). At the end of the year it will be seen south of the Pleiades, setting about three hours before sunrise.

The Star of Bethlehem This month Venus is an evening star, and by Christmas it will be visible for more than two hours after sunset, far outshining anything else in the night sky apart from the Moon. Inevitably, many people will wonder whether it can in fact be the legendary Star of Bethlehem.

At first sight the suggestion seems logical enough. Venus is a glorious object, and at its best it can even cast shadows. Yet a little consideration will show that the idea is untenable. We know very little about the Star of Bethlehem (it is mentioned once in the Bible, and there are no other accounts of it), but if the reports are to be trusted it follows that the Star was something unusual and of short duration. There is nothing in the least unusual about Venus, and many people at Herod's court and elsewhere would have known it; we may be confident that it would have excited no comment whatsoever. The Star was not Venus or any other planet, and suggestions that it may have been two planets close together have been found to be equally untenable.

Rigel Orion is coming back into the evening sky, and will be very conspicuous through to the end of the spring. Its two chief stars are quite unlike each other. Betelgeux is a huge red giant of spectral type M; Rigel is of type B8, with a very high surface temperature (over 20,000°C).

Rigel is very remote. Its distance is difficult to measure accurately, but is thought to be about 900 light-years, so that we are now seeing it as it used to be in the time of William the Conqueror. Yet it still appears as the seventh brightest star in the sky, and is only fractionally inferior to Capella and Vega, though it never rises so high above the horizon. Its luminosity must be of the order of 50,000 times that of the Sun.

Like all normal stars, Rigel is producing its energy by nuclear transformations taking place inside it. As it radiates, it is losing mass, and is using up its 'hydrogen fuel'. With the Sun, a relatively mild Main Sequence star of type G, the mass-loss amounts to 4,000,000 tons per second; with Rigel the loss is much greater, and the evolutionary sequence must be run through much more quickly. The Sun is not expected to alter much for at least 6,000 million years in the future, but long before then Rigel will have left the Main Sequence and passed into the giant branch, becoming a red star similar to the present-day Betelgeux. Since

it is extremely massive, it may well end its brilliant career in a supernova explosion, sending much of its material away into space—though we have to admit that our knowledge of the early and late stages of a star's evolution is far from complete, and it is not certain whether all massive stars become supernovæ.

Rigel has a companion of magnitude 6·7 at a distance of 9·4″. The pair are said to provide a test for a 2-inch telescope; a 3-inch instrument will show it easily. The position angle is 202°.

The Russian Reflector The past few years have seen a tremendous increase in our knowledge of the more remote parts of the universe. Radio telescopes have played a vitally important rôle, but without large optical telescopes the rate of progress would have been very slow indeed.

The Palomar 200-inch reflector came into use in 1948. It was then twice the size of any other telescope in the world; its nearest rival was the Mount Wilson 100-inch, though since then several other telescopes of between 100- and 120-inch aperture have been constructed. The Palomar instrument—known as the Hale reflector, in honour of George Ellery Hale—is still pre-eminent; it can photograph objects far beyond the reach of any other instrument, and it has been responsible for many fundamental advances in our knowledge. Now, however, it may soon be rivalled, since the Russians are working upon their new 236-inch reflector.

With telescopes of this size, the mechanical problems are comparable with those of the actual optics, and the Russians have decided upon an altazimuth mount. This makes the engineering simpler, but it means that the driving mechanism has to be much more complicated, since, in effect, two drives are needed instead of one. The latest indications are that the project is progressing well, and that the telescope will be in action before long. Its site, in Siberia, is not so favourable as that of the Hale telescope, but conditions there are as good as can be found anywhere in the Soviet Union.

It is too early to say how successful the 236-inch will be. No

doubt the optics will be excellent, but everything depends upon the degree of atmospheric interference. When the first results from it are available, astronomers will be able to decide whether it will be practicable to build an even larger instrument; it might be found that the 236-inch is the useful limit, in which case the next increase in aperture will have to await the construction of a full-scale observatory either in space or (more probably) upon the surface of the airless Moon.

The 236-inch is of purely Russian construction; the mirror was made in Leningrad. Up to now, the largest Soviet telescope has been the 102-inch reflector at the Crimean Astrophysical Observatory, also Russian-built. This instrument has been very successful, and has played a major rôle in current astrophysical research.

Eclipses in 1971

In 1971 there are five eclipses, three of the Sun and two of the Moon.

1. *A total eclipse of the Moon* on 10 February, the beginning visible in the British Isles, the entire eclipse visible in America. The shadow of the Earth will first be seen on the left of the Moon's disk at $5^h\ 52^m$ G.M.T. and the eclipse becomes total at $7^h\ 03^m$. In latitude 52°, sunrise occurs at $7^h\ 26^m$ and the Moon sets totally eclipsed at $7^h\ 33^m$. The final stages of the eclipse may be seen in the U.S.A., totality ending at $8^h\ 26^m$ G.M.T., and the shadow passing off the Moon at $9^h\ 37^m$ G.M.T.

2. *A partial eclipse of the Sun* on 25 February will be visible in Europe. In southern England the eclipse begins at $8^h\ 37^m$ G.M.T. and reaches its maximum phase at $9^h\ 40^m$ when about two-thirds of the northern part of the Sun will be covered by the Moon. The eclipse ends at $10^h\ 46^m$ G.M.T.

3. *A partial eclipse of the Sun* on 22 July of very small magnitude is visible only in eastern Siberia and parts of the Arctic Ocean.

4. *A total eclipse of the Moon* on 6 August will be visible in most of Asia, Africa, and Australasia, but only the end will be seen in the British Isles. The eclipse begins at $17^h\ 55^m$ G.M.T. and becomes total at $18^h\ 53^m$. In latitude 52°, sunset is at $19^h\ 43^m$, and the Moon rises at $19^h\ 38^m$ totally eclipsed. The shadow begins to move off the Moon's disk at $20^h\ 33^m$ and the eclipse ends at $21^h\ 31^m$ G.M.T.

5. *A partial eclipse of the Sun* on 20–21 August is visible only in Australasia and parts of the Antarctic, where about half of the Sun's disk will be seen obscured by the Moon at the maximum phase.

Occultations in 1971

In the course of its journey round the sky each month, the Moon passes in front of all the stars in its path, and the timing of these occultations is useful in fixing the position and motion of the Moon. The Moon's orbit is tilted at more than five degrees to the ecliptic, but it is not fixed in space. It twists steadily westwards at a rate of about twenty degrees a year, a complete revolution taking 18·6 years, during which time all the stars that lie within about six and a half degrees of the ecliptic will be occulted. The occultations of any one star continue month after month until the Moon's path has twisted away from the star, but only a few of these occultations will be visible at any one place in hours of darkness.

There are only four first magnitude stars that can be occulted by the Moon; these are Regulus, Aldebaran, Spica, and Antares. During 1971, the series of occultations of Antares will continue every month, but Regulus will cease to be occulted in April. The planets Mercury and Venus are also occulted during the year, but none of these events is visible in the British Isles.

Comets in 1971

The appearance of a bright comet is a rare event which can never be predicted in advance, because this class of object travels round the Sun in an enormous orbit with a period which may well be many thousands of years. There are therefore no previous records of the previous appearance of these bodies, and we are unable to follow their wanderings through space. The comets of short period, on the other hand, return at regular intervals, and attract a good deal of attention from astronomers. Unfortunately they are all faint objects, and are recovered and followed by photographic methods using large telescopes. Most of these short-period comets travel in orbits of small inclination which reach out to the orbit of Jupiter, and it is this planet which is mainly responsible for the severe perturbations which many of

these comets undergo. Unlike the planets, comets may be seen in any part of the sky, but since their distances from the earth are similar to those of the planets their apparent movements in the sky are also somewhat similar, and some of them may be followed for long periods of time.

The following short-period comets are among those most likely to be recovered in 1971:

Comet Encke has the shortest period (3·3 years) of any known comet and has made forty-eight returns to perihelion since it was first discovered in 1786. Its small but very eccentric orbit can carry it inside the orbit of Mercury.

Comet Ashbrook-Jackson was discovered in 1948 and was last seen at its return in 1963. It has a period of 7·4 years and travels in an orbit of small eccentricity which lies wholly outside the orbit of Mars.

Comet Arend-Rigaux was discovered by two Belgian astronomers in 1950, and was seen again in 1957 and 1964. It has a period of 6·8 years.

Comet de Vico-Swift was recovered in 1965 as a result of new calculations, after having been lost since 1894. It has a period of 6·3 years, and is expected to return at the end of 1971.

Comet Neujmin (2) is another comet whose return has been predicted on the basis of modern calculations. It has a short period of 5·5 years, and was last seen in 1927.

Comet Wolf-Harrington is a faint comet with a period of 6·5 years. It was discovered by Wolf in 1925 and not seen again until 1951 when it was recovered by Harrington. The returns of 1957 and 1965 were also observed, and it is expected again in July 1971.

Comet Daniel was discovered in 1909, but was not recovered until 1937. It was also seen in 1943, 1957, and 1964. This is an interesting comet, with a high inclination of twenty degrees, and a period of 7·1 years.

Comets Tsuchinshan (1) and *Tsuchinshan* (2) were both discovered in 1965 at the observatory on Purple Mountain, Nanking. They both made a close approach to Jupiter in 1961, and have periods of 6·6 and 6·8 years respectively.

Comet Schwassmann-Wachmann (1) has a nearly circular orbit with a period of 16·1 years, which lies entirely between the orbits of Jupiter and Saturn. It behaves very much like a planet and is visible each year. This comet is remarkable because it undergoes changes of brightness, which seem to have some connection with solar activity.

Meteors in 1971

Meteors ('shooting stars') may be seen on any clear moonless night, but on certain nights of the year their number increases noticeably. This occurs when the Earth chances to intersect the orbit of a meteor swarm, which is a concentration of meteoric dust moving in an orbit around the Sun. Such an intersection can occur only at one particular time of year, but if the dust is spread out along the orbit, the resulting shower of meteors may last for several days.

The following table gives some of the more easily observed showers, with their radiants; the effect of moonlight in 1968 is indicated.

Limiting dates	*Shower*	*Maximum*	*R.A.*	*Dec.*	*Notes*
Jan. 3–4	Quadrantids	Jan. 3	$15^h\ 28^m$	+50°	
April 20–22	Lyrids	April 22	$18^h\ 04^m$	+33°	
July 27–Aug. 17	Perseids	Aug. 12	$3^h\ 04^m$	+58°	
Oct. 15–25	Orionids	Oct. 20–21	$6^h\ 24^m$	+15°	
Oct. 26–Nov. 16	Taurids	Nov. 1–7	$3^h\ 36^m$	+14°	M
Nov. 15–17	Leonids	Nov. 16	$10^h\ 08^m$	+22°	
Dec. 9–14	Geminids	Dec. 13	$7^h\ 28^m$	+32°	
Dec. 20–22	Ursids	Dec. 22	$14^h\ 28^m$	+76°	

M = moonlight interferes

Minor Planets in 1971

Although there are many thousands of minor planets, only about 2,000 have well-determined orbits, and are listed in the catalogues. Only the 'big four', Ceres, Pallas, Juno, and Vesta can reach any considerable brightness; Vesta can occasionally be seen with the naked eye. There is an opposition of Vesta this year on 22 July, when the planet reaches magnitude 5·7—just visible to the naked eye, but readily to be found with the aid of binoculars. The path of Vesta at this time is shown in the diagram on page 80. Of the other three minor planets, only Pallas comes to opposition in 1971, but its magnitude at this time (19 November) is only 7·4.

Some Events in 1972

ECLIPSES

In 1972 there will be four eclipses, two of the Sun and two of the Moon.

16 January—An annular eclipse of the Sun visible only in the Antarctic.

30 January—a total eclipse of the Moon, visible in Australasia and America.

10 July—a total eclipse of the Sun, the central track crossing Siberia, northern Canada, and Newfoundland.

26 July—a partial eclipse of the Moon, visible in the Americas.

THE PLANETS

Mercury will be visible as an evening star at greatest eastern elongation on 14 March, and as a morning star at western elongation on 25 August.

Venus will be at eastern elongation as an evening star on 8 April, and is in inferior conjunction on 17 June. After this it will be a morning star, and reaches greatest western elongation on 27 August.

Mars is an evening star until conjunction on 7 September, and will be a morning star after this date. There is no opposition of Mars in 1972.

Jupiter is at opposition on 24 June in Sagittarius.

Saturn will be well placed in Taurus, and is at opposition on 8 December.

Uranus is at opposition in Virgo on 5 April.

Neptune is at opposition on 24 May in Scorpius.

Pluto is at opposition on 21 March.

PART TWO

Article Section

The same plan has been followed as with previous *Yearbooks*, and the articles range from home-built observatories to the exploration of the planets, problems of positional astronomy, and philosophical comments. Biographical notes about our contributors will be found on page 186.

An Observatory Dome for Amateurs

R. A. G. GULLEY

There is no doubt that most keen amateur astronomers have a great desire to own their own dome, and many would like to tackle the task of building one. I became interested in this project because my cousin, Patrick Moore, was no exception, so I offered to build a dome to house his $8\frac{1}{2}$-inch reflecting telescope, and began to work out how to set about this task. This dome, which has now been in constant use for many years, has proved successful in every way, and to build this is well within the ability of any average handyman. It must however be emphasized that accuracy is essential to obtain perfect results.

When working out the dimensions of the base it should be appreciated that to build this as small as possible, to house the telescope, would be a fallacy. Once the base is completed and fitted with shelves, and there are one or two persons inside, any restrictions of space would be a great hindrance. The base should therefore be about two feet larger in diameter than the overall length of the telescope.

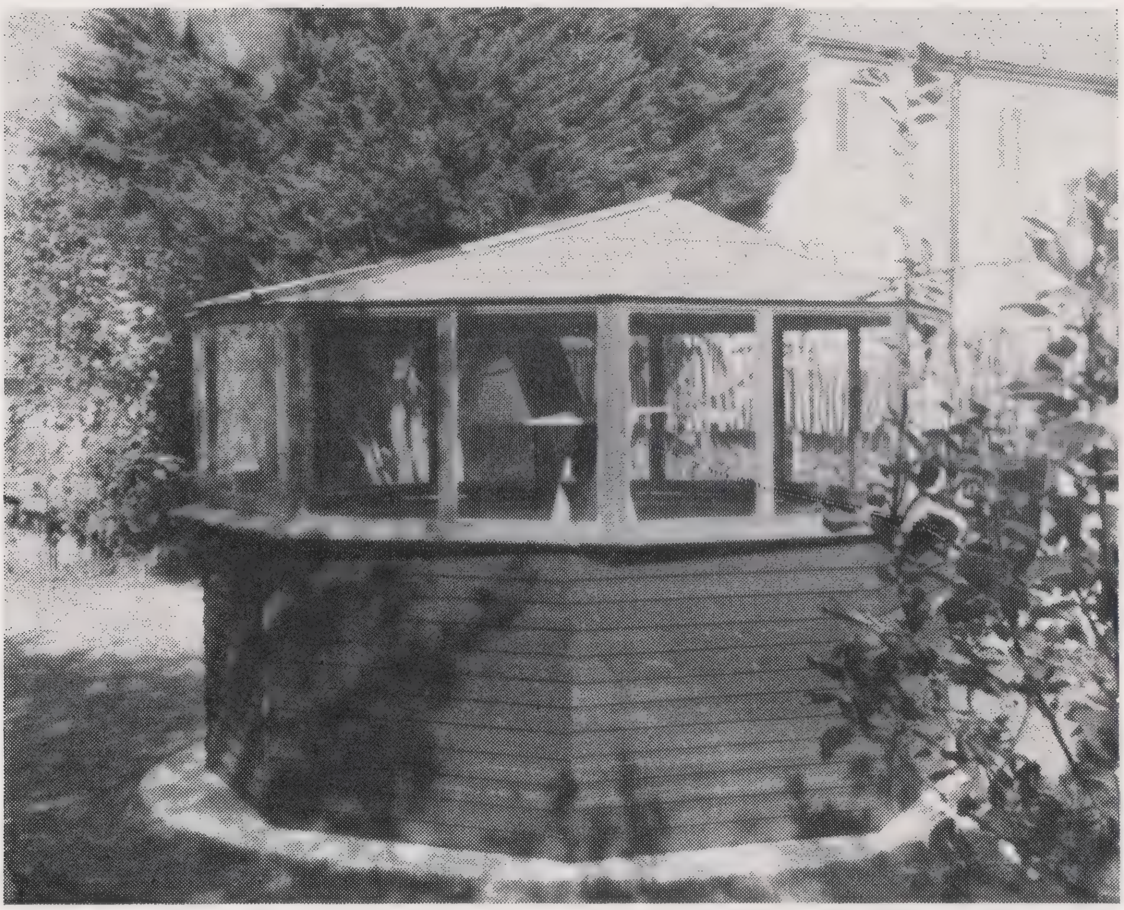
To construct a base is not a difficult task; but as the dome has to revolve on a circular rail, this must have at least eight fixing positions to take the weight of the dome. An octagonal structure is therefore the most satisfactory method to adopt, as it allows for fixing on each section and has the added advantage of being an attractive building. It is only necessary to build eight frames, and to bolt these together at 135°, to complete the base.

The actual height of the base is entirely dependent on the lowest horizon required for viewing, but it is unlikely that this would be less than 3 feet 6 inches. Each frame can be built of

2 inch by 2 inch timber with a single cross member from corner to corner. The joints should be fitted with a mortise for strength, and the ends facing the next frame should be planed to the correct angle for bolting. Weather boarding can then be nailed to the frame to complete the structure. Naturally, one frame must be constructed differently, as it must hold the door; the door itself can be made the same as the other seven frames, but smaller. The door should be as large as possible inside the frame, as when entering in a bent position a considerable width is required for easy access.

Once the base is completed, the more interesting part of the work begins. It is now time to make the circular rail on which the dome is to revolve. I decided to use a fairly heavy gauged material which would bend easily, and I chose aluminium strip. The gauge was $\frac{7}{16}$ inches by 1 inch, and I used 10-foot lengths bolted together. It is unlikely that many people would be able to roll the metal into a curve, or that they would be able to get this job done, and I felt that it would be a challenge to try this part of the operation myself. I was very surprised to find that a perfect curve could be constructed by using an ordinary vice with three nails. By fixing two nails on each end of one face of the jaws, and the third nail in the centre of the opposite face, it was necessary only to slip the aluminium strip through, one inch at a time, with exactly the same pressure on the vice handle, to obtain the desired result. To get the exact leverage I fixed a tube about two feet long over the vice handle and arranged a stop on the bench beyond which the lever could not pass. Trial and error was necessary until the curvature exactly matched a curve which I had chalked out on the ground to fit the frame already made. Once the position of the vice lever was determined, it was a slow, monotonous job to slip several lengths of strip aluminium through the vice. Each length was checked for accuracy when completed, and I found it was necessary to cut about two inches off each end.

It must be remembered that this rail cannot be fixed directly to the base frames, as the ball bearings have to run on the rail.



Patrick Moore's dome (8½-inch reflector)

I therefore allowed for a 1-inch spacer to be fixed between the rail and the frame. For this I used bakelite rod, but any material could be used. The rail was fixed by means of very large wood screws, but these have to be very accurately countersunk on the inner surface of the rail, as it is against this surface that the bearings for the side thrust of the dome run.

Once the rail is completed, the next task is to make the revolving platform on which the dome will be built. This I built of ordinary $1\frac{1}{2}$-inch angle iron, and quite simply made up an angle iron frame to match exactly the eight base frames. Once eight lengths were cut with the ends at the correct angles, each length was bolted together with joining strips on both faces. Obviously each corner had to be very considerably strengthened, and this was done with another piece of angle iron across the inside, so positioned that the centre of the inner vertical edge was about $\frac{1}{4}$ inch outside the circular rail. This has to be made very accurately, as it is at this centre point that the ball bearing taking the weight of the dome is fixed. I found that it was not necessary to use any larger bolts than 2 BA. When the frame is completed in this fashion, it will be found to be very strong and rigid.

Now the most interesting part of the construction begins, as it is at this stage that the bearings assembly must be made. Each assembly must hold two ball bearings, one large one to take the weight and the other a smaller bearing acting sideways to centralize the dome. There are no doubt many methods of constructing this assembly, and after considering all the alternatives I decided to use a silver steel rod of about 1 inch diameter; I turned up a special mounting to hold the main weight carrying bearings. This is not difficult for anyone able to use a lathe, as all that it entailed was to turn down a surface to fit the internal bearing diameter, remembering that once the bearing is in position there must be about $\frac{3}{4}$ inch of the rod protruding, which can be turned down to make a $\frac{3}{8}$ inch bolt. When this rod is bolted to the centre of the angle iron frame, the bearing should be positioned exactly above the running rail. There must

also be about two inches of the rod protruding on the inside of the bearing, so that the second bearing can be attached at right angles to the main bearing. By placing the smaller bearing against the side of the rail with the main bearing on top in position, it is only necessary to drill a vertical hole through the main rod in line with the small bearing centre, and the same size; a bolt can then hold the bearing and extend right through the main rod with a lock nut on either side. Slight adjustments will undoubtedly be necessary to take up any play before the frame will revolve with all the eight main bearings remaining centrally on the rail. I would point out that in my case the first trial run was hopeless, but after only a few adjustments success was achieved.

From this point on it is known that the dome will work, and all that remains is to build a suitable structure to suit individual requirements. In my case I decided to have glass sides, as this adds to the appearance and also makes it far easier to select the viewing position. There is the added advantage that very light frames can be made to hold the glass, making assembly easier, as the glass was not to be fitted until the whole dome was completed. I would not suggest using one large window for each side, but having two for each side, as this will avoid cracking due to any twist which may occur when revolving the dome. Once again there must be one special frame to hold an opening window; this frame must be made without any cross member above the window, which would prevent viewing. The size of the opening window should be about 2 feet 6 inches to allow for ample viewing time before it is necessary to rotate the dome again, and consequently it is necessary to make two small windows, one on either side of the opening window, to make the full size frame. The height of each of these window frames is entirely dependent on the total height required, and each frame can be bolted to the angle iron base with a small bracket bolted to each pair at the top. I decided to make these brackets of duralumin, cut from a sheet of about 10 gauge, as in this way I reckoned that if there were any undue twist they would break, thus showing a weakness in design. However, the original

brackets are still in use, and show no sign of fracturing. It seems to me that this is therefore a very good material to use, as it is very easy to drill, cut, and bend, and it will not rust.

It is now time to begin the roof, and once again I made this in eight sections. In this case, however, it is essential to make each one separately, as no two are exactly similar. It must be borne in mind that to enable the telescope to be set at a vertical position, the opening section of the roof must begin at the top of the opening side window and extend about eight inches beyond the centre and highest point. The width of the top opening section should be 2 feet 6 inches or the same as was allowed for the side opening. It is now only necessary to make a simple frame out of light timber about 2 inches by 1 inch fixed at the top of each side of the window top, and extending as suggested about eight inches beyond the centre, inclined at the angle at which the roof will be built, with the ends joined by a similar piece of timber 2 feet 6 inches wide. At this stage it will be necessary to have a support in the centre of the dome to hold the sections up until they are all fixed together at the top. Once the opening is in position, it is quite a straight-forward task to make the remaining frames from each corner to the top. As light a structure as possible is essential, and I used marine plywood, about $\frac{1}{8}$ inch, covered by roofing felt. Once again I bolted each section together, and used duralumin sheet for the joining plates. The only remaining roof section to complete now is the door for the 2 feet 6 inch-wide opening up to the top. I felt that it would be advisable to have two opening hatches to avoid extra strain on the fairly light roof frames. In order to make these openings completely waterproof when shut, the hatches must fix over a beading like a box lid. It is best to have the hatches opening on opposite sides of the frame. The lower hatch must shut first in order that the top hatch can have an extended lip to overlap the lower hatch; this has proved very successful.

At this stage all the real building has been completed, and all that remains to be done is to work out the number of fittings

required. The most essential of these is a lever for opening the top hatch, as this is out of reach. In this case I found that the best method was to have a long metal rod fixed to the opening side of the hatch and to have a block of wood about 4 inches by 2 inches fixed to the hatch close to the hinge side. When opening, the hatch is first lifted to a vertical position by the rod and the rod is then rested against the wooden block, so that the hatch can be lowered quite gently on to the roof. The lower hatch can be opened by hand from outside, and therefore needs no fittings. It will be noticed that when the hatches are open they will not rest squarely on the roof, so rests must be made to save any strain or warping; I fixed these to the hatches themselves made out of $\frac{1}{2}$ inch-wide strip steel, and screwed to the wooden hatch frames.

The dome, from an operational point of view, is now completed, but it will be found that there are several improvements which will be very useful. First, as the dome revolves freely, it will be necessary to fix some form of brake to prevent it from revolving in a strong breeze. This can undoubtedly be done in many ways, the simplest being to attach two guy ropes, but after taking so much trouble in building the dome this system would be rather shoddy. I found that it was possible to fix a brake unit beside one of the bearing mountings, so that when the lever was pulled two blocks gripped the circular rail. This was quite simply a lever pressing on a spring-loaded cam when in a horizontal position, and releasing the pressure when the lever was in a vertical position.

No doubt most builders would feel that to fix panels to the inner sides of the base would finish off the job, and shelves can then be built to keep eyepieces and any papers required. Shelves are essential, as when working in the dark one should be able to know exactly where any piece of equipment has been placed.

Lastly, a small light will help but it must be remembered that this should be only of very low power. Sufficient light can be obtained by an ordinary torch bulb and battery, and a switch can be situated by the door for easy access.

I must stress that a dome of this type cannot be built in a few weeks, and will probably take the average amateur about four months. The time will however be very well spent, and the satisfaction of having made one's own dome can only be realized after achieving such a task.

I would like to make it clear that in making this dome I was assisted by my nephew, Brian Gulley, and it was as a result of combining both our ideas and methods of manufacture that our final success was achieved.

Positional Astronomy

GILBERT E. SATTERTHWAITE

There is today a tendency to regard positional astronomy as rather dull and old-fashioned. This is regrettable, for it is in fact a most interesting, progressive, and important field. Until the development of the spectroscope and its application to astronomical studies by Wollaston and Huggins in the early 19th century, much of the progress in observational astronomy was in this field, and 18th-century astronomy was hardly static. Even today, when the achievements of space technology have added a new dimension to the study of the heavens, and astrophysical research occupies a large percentage of available telescope time, positional work remains a vital part of astronomy.

The subject may be described as the branch of astronomy which is concerned with determining the positions of celestial objects; as these are not stationary but are constantly moving relative to each other, it is necessarily concerned with their motions also. The determination of the apparent positions of the stars is an essential ingredient in attempts to measure their relative distribution in space, and hence in studies of the structure of the galaxies. Our knowledge of the motions of all heavenly bodies—including the planets, comets, and satellites of the solar system—is also obtained from repeated observations of their positions made over long periods of time. It is clear, therefore, that observations of *position* must be accompanied by equally precise measurements of the passage of *time*: indeed, time determination is a vital and integral part of positional astronomy. Although it might be thought to be merely a matter of mechanical or electronic timekeeping, in practice it is essential to relate 'clock time' to time determined by astronomical observation.

The observations involved in positional astronomy consist of making accurate measurements of the *place* of an object—that is, its position relative to other heavenly bodies at a precisely determined instant. The position is measured in suitable co-ordinates—usually Right Ascension and Declination.

The R.A. and Dec. are measured from the equinox and the equator respectively. Unfortunately these are slowly changing their own positions on the celestial sphere, due to precession. If, therefore, we wish to keep an accurate record of several observed positions of a star for later intercomparison, we must calculate what the co-ordinates of each observed place would be if measured from the position of the equator and equinox at a specified time. When the place is referred to the equator and equinox at the instant of observation, it is termed an observation 'referred to the true equator and equinox of date'.

The following discussion refers, for simplicity, to the place of a star, but the same considerations apply, of course, to observations of planets and other objects.

There are three basic forms of a star place—the apparent place, true place, and mean place. The *apparent place* of a star is its actual position on the celestial sphere, measured from the true equator and equinox of date. The apparent place also gives the R.A. and Dec. as observed from the Earth—that is, measured on the *geocentric* celestial sphere. If we apply to the apparent place corrections to take account of annual parallax and aberration, we obtain the position of the star as it would have been observed from the Sun, i.e. on the *heliocentric* celestial sphere. This is termed the *true* place of the star. If the calculated true place is then referred to the equator and equinox for the beginning of the year in which the observation was made, it becomes the *mean place*.

In order to analyse large numbers of observations of the position of a star, all made at different times, it is necessary first to reduce them all to a common epoch. Whereas the mean place is sufficient for short-term projects, longer programmes involving the comparison of observations made over several years require

that they are all reduced to a *standard epoch*. The standard epoch currently in use is 1950·0; prior to 1925 it was 1900·0. To reduce an observation to the standard epoch the observed apparent place must be corrected for the combined effects, during the interval between the standard epoch and the moment of observation, of precession, nutation, aberration, annual parallax, and proper motion.

There are two main branches of positional astronomy—meridian astronomy and photographic astrometry. Meridian observations are made by direct observation with specially designed telescopes, whilst astrometric observations are made by the subsequent measurement of images on a photographic plate which has been exposed in a more conventional telescope.

The instruments used in meridian astronomy are designed to ascertain the sidereal time at which a body transits the observer's meridian, from which its R.A. can be calculated. The Dec. can be measured from the setting of the instrument. Meridian instruments are finely engineered and give results of great precision, but their size—and consequently the faintness of the objects they can observe—is limited.

The instruments used in photographic astrometry—called *astrographic telescopes* or *astrographs*—can be made much more powerful. This, together with the cumulative light-gathering power of long-exposure photography, permits the observation of much fainter objects than with meridian instruments. It is not however possible to construct a large astrograph with the same engineering precision as a meridian telescope, and so positions obtained with it are significantly less accurate.

The Uses of Positional Astronomy

Positional observations are used for many purposes. One of the most important is the compilation of catalogues of star places. In his George Darwin Lecture to the Royal Astronomical Society in 1936, Professor A. Kopff of Heidelberg, still one of the world's leading experts in this field, said: 'We must continue to study the motions in the Universe, both near and distant, more

exactly and more in detail; and we are glad that we can go back to our star catalogues—often a little despised—as the foundation of our science.' Kopff's words have not gone unheeded, and far from being despised, star catalogues of ever increasing accuracy and covering the special requirements of all types of astronomer have been produced in large numbers. Most star catalogues record not only the R.A. and Dec. of each star at a selected epoch, but also additional information, which may include the apparent magnitude, spectral class, proper motion, parallax, etc.

One of the most important kinds of star catalogue is the *fundamental catalogue*. This utilizes the absolute positions of a selected list of relatively bright stars distributed throughout the heavens. By combining many observations made with meridian instruments at observatories throughout the world, their positions and proper motions can be determined with great accuracy. These are the *fundamental reference stars* whose positions are then assumed in order to calibrate observations of fainter stars made partly with meridian instruments and (especially) with astrographs.

Another important function of meridian astronomy is the regular observation of the ever-changing positions of the Sun, Moon, planets, and the brighter asteroids. Long and continuing series of such observations are needed in order to produce the ephemerides of their future movements published in the national almanacs for the benefit of observers and navigators alike.

A number of important studies are carried out by photographic astrometry. Among them are programmes for the determination of the distances of stars by measuring their trigonometric parallax, using the diameter of the Earth's orbit as baseline. This is done by comparing their positions on astrographic plates exposed at six-monthly intervals. Other programmes involve the comparison of places obtained at much longer intervals, for the determination of proper motions. One valuable product of proper motion programmes is that they enable one to identify the true members of an open cluster: if from their

proper motions we find that certain stars share a common direction of motion, and if radial velocity or parallax observations indicate that they are all at approximately the same distance from the Earth, then they clearly constitute a genuine cluster. Analyses of this kind are of immense value to astrophysicists.

Meridian Astronomy

Meridian observations fall into two main categories, both of importance to positional astronomy, as we have seen: observations intended for the determination of astronomical time and those made in order to determine the place of a celestial object.

The principle of an observation for the purpose of time determination is that the meridian transit of a star is timed against an observatory clock; the star chosen is a fundamental reference star whose place is so well known that it can be assumed. As its R.A. is known, the sidereal time of transit over the observer's meridian can be predicted: the difference between the predicted and observed times of transit represents the error of the clock.

Meridian observations of place comprise two measurements—the zenith distance of the object at transit and the sidereal time of transit, from which the Dec. and R.A. respectively can be calculated. In this case the time is assumed—after making any necessary allowance for known errors of the clock—so that the observation is in fact a measurement of the object's R.A. expressed in time.

The principal instrument used in meridian astronomy is the *transit circle*. This is based upon two earlier instruments, the development of which is attributed to Ole Rømer, the 17th-century Danish astronomer: the transit instrument and the meridian circle.

The *transit instrument* comprised a refracting telescope with a mechanical axis fitted on to its tube, perpendicular to the optical axis, which was supported at both ends by Y-bearings. The mechanical axis was erected on an east-west line, enabling the telescope to be rotated in the plane of the meridian. An early

example of the transit instrument still in existence is that constructed for Halley and erected in 1721 at the Royal Observatory at Greenwich, where it can still be seen. With the transit instrument the observer was able to time the meridian passage of an object and hence determine its R.A.

The *meridian* or *mural circle* was a logical development of the earlier sextants and octants, the scale being extended to form a complete circle. This was mounted on a wheel-like structure of iron with a mechanical axis fitted through its hub. The instrument was again mounted with the mechanical axis east–west, enabling the circle to be rotated in the plane of the meridian. A sighting telescope was fixed along a diameter of the circle, and a pointer and microscope provided to permit the setting of the circle to be read off. From this the zenith distance of the star could be calculated. In later versions the circle was fixed and the telescope pivoted to rotate at its centre, the setting of the telescope being read off against the circle by means of pointers and microscopes at intervals around the circle. A well-known example of this later type is one constructed in 1812 by Troughton for the Royal Observatory, Greenwich; it is still preserved there.

It is possible that meridian observers during the late 18th and early 19th centuries realized the possibility of combining the functions of the transit instrument and the mural circle into a single instrument, and may have attempted to put the idea into practice. The credit for designing an instrument specifically for the dual purpose, however, belongs to Sir George Airy, the seventh Astronomer Royal, who was probably the most versatile scientist of his day and undoubtedly the foremost practical astronomer of the 19th century. Formerly Professor of Astronomy at Cambridge, Airy was appointed Astronomer Royal in 1835 and immediately set about the total re-equipment of the Royal Observatory (as well as the total reorganization of its staff and methods of work).

In addition to his great mathematical and scientific ability, Airy was also a highly competent engineer. It was therefore his

practice to design all his new instruments himself; it would require a separate article to describe the long list of successful instruments he created.

Probably the most important of all Airy's instrumental innovations was the Transit Circle which now bears his name, erected at Greenwich in 1851. Specifically designed to make observations in both Right Ascension and Zenith Distance, the instrument set the pattern for a new generation of meridian instruments. The new instrument was built to Airy's detailed designs by Messrs Ransome & May of Ipswich, with a 9-inch object glass by Simms. A number of minor modifications were made to the transit circle and its ancillary equipment from time to time, but it retained essentially the same form throughout its working life, which lasted for an unparalleled 103 years. The first observation was made by Airy's Chief Assistant, Thomas Ellis, on the night of 4–5 January 1851; the last was made on 30 March 1954*.

The Airy Transit Circle remains in position and will continue to do so, for it defines the Greenwich meridian, adopted as the Prime Meridian of zero longitude by an international conference held in Washington in 1884.

When first erected, the Airy Transit Circle utilized the 'eye-and-ear' method of timing meridian transits, as used by observers with the earlier transit instruments. The observer listened to seconds pulses from the observatory clock and mentally interpolated the times of the star's passage across several fixed vertical wires in the telescope field. In 1854 Airy's inventiveness added another important technique to meridian astronomy, and his transit circle became the first to be fitted with equipment for the electrical recording of transits. This was further improved in 1915 by the addition of an impersonal micrometer.

At this point we may consider in more detail the methods of observation used with the Airy Transit Circle, for they illustrate very well the principles involved and also help us to understand the more complicated techniques used in modern instruments.

* By the author of this article!—EDITOR

Observation in Right Ascension

Let us assume that the instrument is correctly set up, with its optical axis in the plane of the meridian. The telescope is rotated around the mechanical axis until it is set at the appropriate altitude for the star to be observed. Reference to the sidereal clock will indicate when meridian passage is due, the local sidereal time of transit having been calculated in advance. The star will cross the field horizontally from east to west (west to east for circumpolar stars at lower culmination). The altitude setting of the telescope is adjusted until the star is travelling across the centre of the field—i.e. along H–H′ in Figure 1, which shows the field of the telescope looking north.

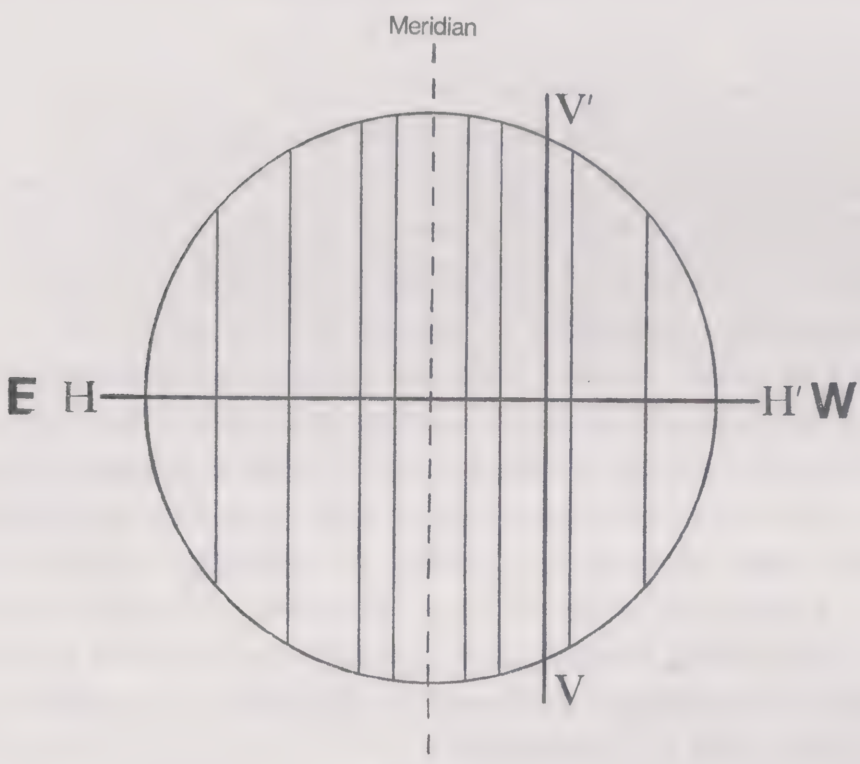


Fig. 1

In the early days of electrical recording, the observer timed the passage of the star past the fixed vertical wires (see Fig. 1) with a hand-tapper which sent an electrical impulse to a recording chronograph on which seconds pulses from the sidereal clock were also registered. This method was subject to considerable

personal errors, which varied from one observer to another, and the *impersonal micrometer* was devised to reduce these errors. In this method the telescope was provided with a movable vertical wire (V–V′) which could be traversed across the field by smoothly rotating a pair of knobs with each hand alternately. Its position in the field at any instant could be measured by means of an attached micrometer. The observer's task was to move the wire across the field at the same rate as the image of the star, keeping the star bisected with the wire all the while. The time at which the star passed certain points in the field was then recorded by impulses sent automatically to the chronograph. The chronograph trace was measured subsequently and the time of meridian passage calculated.

Observation in Zenith Distance

The exact position of the star above or below the centre of the field was measured with the aid of the movable horizontal wire H–H′, which was also provided with a micrometer. The micrometer was attached to a drum covered by a paper strip, which could be punctured by means of a small 'pricker'. As the star passed each vertical wire its image was bisected with the moving wire H–H′ and the drum pricked. Later the pricks could be set against a fiducial mark and micrometer readings taken. As soon as the observation was complete, and before the telescope was moved, its setting in altitude was determined, using a graduated circle of large diameter attached to the telescope tube, and six microscope/micrometers trained on it at 60° intervals. From these two sets of readings the observed Z.D. of the star could be calculated.

In recent years further modifications leading to improved accuracy have been made to the transit circle. It is now usual for the moving R.A. wire to be driven by an electric motor, the observer keeping the star bisected by remote control of the motor speed. It is also becoming increasingly common for the R.A. and Z.D. micrometer readings to be fed direct on to punched cards or other form of computer input; the subsequent

calculation of the observed places is then performed by the computer, thus obviating the lengthy calculations formerly carried out by human computers.

Although transit circles are engineered to high precision, no instrument can be perfect, and one of the most important aspects of designing and using them is the problem of minimizing their instrumental errors and—more important still—determining their effect upon the observations and calculating the necessary corrections to the observed places.

These days it is rare for the large transit circles used for positional work to be used to control the national time services. For many years this has been the function of smaller, custom-built, transit instruments (usually of about three inches aperture).

A number of variants of the transit circle have been proposed, notably the *Mirror Transit Circle*, in which the moving part is reduced to a small plane mirror with attached circle, pivoted to rotate in the plane of the meridian, which is used to direct the light of the object under observation into one of two horizontal telescopes fixed in the meridian.

Other Meridian Instruments

A number of very sophisticated meridian instruments have been developed during the past twenty years, some of them involving quite different principles from the transit circle. Probably the most important of these is the *Photographic Zenith Tube* (P.Z.T.).

Although it is a relatively recent innovation in its present form, the ancestry of the P.Z.T. can be traced back to the Reflex Zenith Tube designed by Airy and erected at Greenwich early in the 19th century. A photographic instrument based upon similar principles was developed by F. E. Ross and erected at the U.S. Naval Observatory in Washington in 1915.

The modern form has many refinements, and was designed by D. S. Perfect for the Royal Greenwich Observatory at Herstmonceux, where it was erected in 1955. It is used to determine the zenith distance and time of transit of stars which culminate

very close to the zenith. These measurements can be made with great accuracy; the probable error of transit observations being about $\pm 0{\cdot}005$ seconds of time and of Z.D. observations about $\pm 0{\cdot}05$ seconds of arc. P.Z.T. observations of transit times are principally used to control the national time service, (superseding the small transit instrument for this purpose) and those of Z.D.s for the determination of latitude variation. At least ten P.Z.T.s are now in use at national observatories throughout the world.

The P.Z.T. consists of a photographic refractor, permanently mounted in the vertical so that it is directed towards the zenith. The length of the telescope tube is halved by the introduction of a bath of mercury approximately half way down it. This acts as a horizontal plane mirror, bringing the incoming light rays to a focus at the top of the tube, just beneath the objective. Most of the tube is accommodated in a pit below floor level.

The photographic plate is mounted in a special carriage which is driven across the field by a phonic motor at a predetermined speed equal to the apparent motion of the star across the field due to the Earth's diurnal rotation. This produces point images on the plate, rather than trails. Exposure is controlled by a rotating shutter above the objective.

The plate carriage and object glass are mounted in a heavy rotary, or turntable, which is rotated through 180° between exposures. The full sequence comprises four exposures, the plate being traversed twice across the rotary in each direction; due to the rotations of the carriage between exposures, however, the plate's motion is always in the same direction, following the star.

The four images form a quadrilateral on the plate (WYXZ in Figure 2); the relative positions of these images are measured using a high-precision measuring machine. The required data can be obtained from these measurements. As the carriage is reversed between each exposure, alternate images will fall on either side of the zenith: hence the Z.D. of the star is equal to

half the perpendicular separation of images W and Z, or Y and X, as shown in Fig. 2.

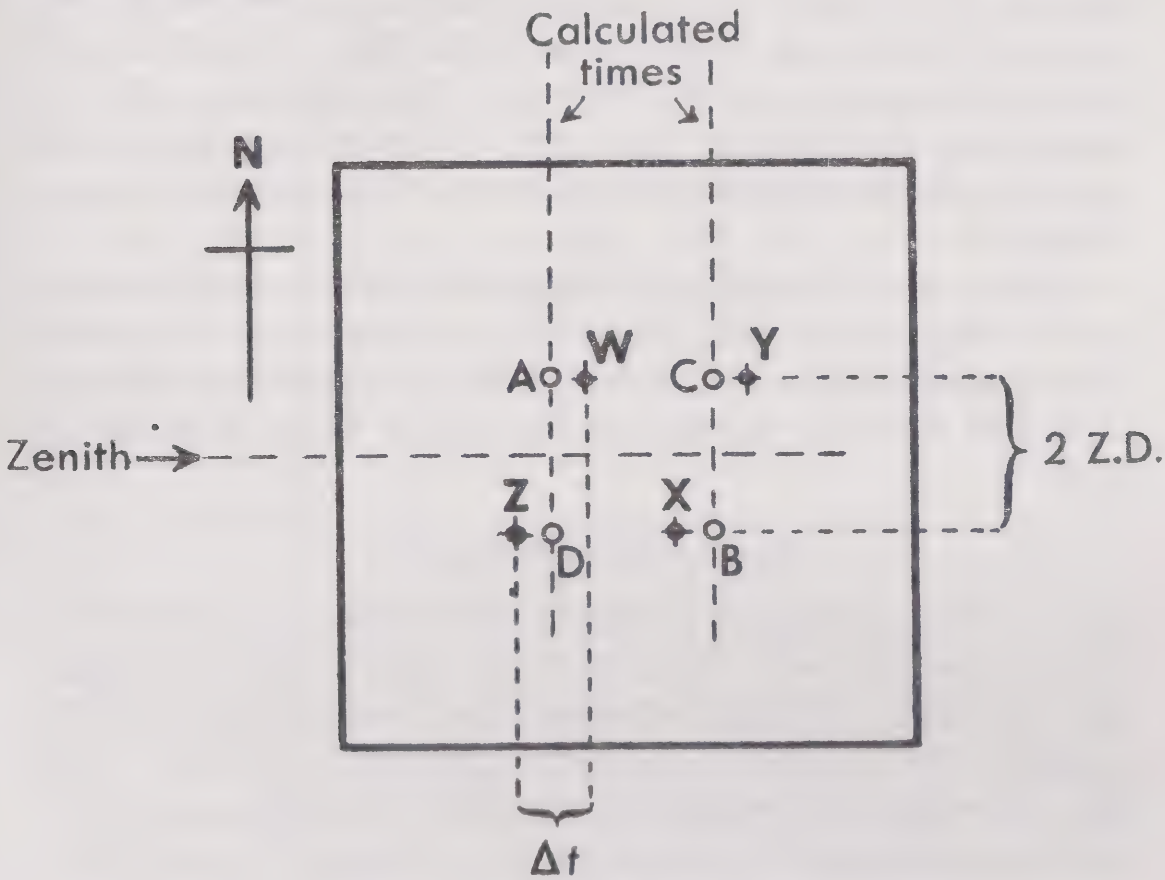


Fig. 2

The exposure cycle is started at a predetermined time related to the expected time of transit of the star. If the error of the observatory clock is zero, the four images will appear in the positions indicated by open circles in Fig. 2 (A,C,B,D). If (as is usual) a small clock error is present, its effect is to displace alternate images to either side of these positions, i.e. to W,Y,X,Z. The size of the clock error (Δt) is given by the perpendicular separation of images W and Z, or Y and X, as shown in Fig. 2.

Despite its great accuracy the scope of the P.Z.T. is limited by the fact that it can only be used to observe zenithal stars; for this reason its use in positional astronomy is to supplement, rather than to replace, the transit circle.

Another important meridian instrument introduced in recent years is the *Impersonal Prismatic Astrolabe*, designed by A. Danjon of the Paris Observatory. This instrument enables an observer to determine very accurately the time at which a star's Zenith Distance is exactly 30°; the clock error can also be determined. Observations made with this instrument are mainly used to control national time services and to measure latitude variation.

A great deal of ingenuity and engineering skill is being devoted to the design of meridian instruments capable of operating with ever-increasing accuracy, so that even the complex instruments described here may be entirely superseded within a decade or two.

Photographic Astrometry

Astrometric observations are made with a telescope of moderate or large aperture, with optics specially designed for photographic use. Both refractors and reflectors have been employed for the purpose. The object is to produce a plate of a relatively large field, showing good images of faint stars. It is important to control the photographic processes so as to minimize such defects as emulsion creep, so that the relative positions of the images recorded on the plate accurately represent the actual positions of the objects photographed.

The positions of star images on an astrographic plate are measured in normal rectangular co-ordinates; from the linear distance between two images the angular distance between the two stars on the celestial sphere can be calculated. The equations used in this conversion include factors related to the optical and mechanical data of the telescope, its exact direction during the exposure, etc.

Photographic astrometry really started in 1882, when David Gill (later Sir David), H.M. Astronomer at the Cape of Good Hope, strapped a hand camera to one of the equatorial telescopes to photograph a bright comet. Using exposures of an hour or two he obtained plates which not only showed the comet but

also many background stars. Gill immediately realized that he had chanced on a method of charting faint stars which was much more rapid and exact than the tedious visual methods previously used. Gill at once commenced a photographic survey of the stars of the southern skies. With the Director of the Paris Observatory, Admiral Mouchez, he organized an international conference to consider the part photography could play in astronomical research. The conference was held in Paris in 1887, and resulted in a world-wide project—the *Carte du Ciel* programme.

The programme was devised with two aims, to produce a photographic chart of the entire heavens, showing all stars down to the fourteenth magnitude, and a catalogue giving the places and magnitudes of all stars down to the eleventh magnitude. The plates required for this vast dual project were to be obtained with similar instruments to be erected at eighteen observatories throughout the world.

The design selected for the *Carte du Ciel* telescope was that of an instrument already installed at the Paris Observatory—a 13-inch photographic refractor of 135 inches focal length. The objectives were doublets, colour-corrected for violet/blue light (wavelength 4000–4800 Ångström units) and designed to produce images free from coma. The area photographed on the plate was a little over 2° square, at a scale specially chosen for convenience of measuring—one minute of arc being represented by one millimetre on the plate. The *Carte du Ciel* astrograph was a pioneering instrument which has made enormous contributions to astrometry; several of them remain in useful service.

One of the most important developments in astronomical photography was the invention of the Schmidt telescope, which gives undistorted images over much wider fields than the conventional refractor, and records much fainter stars in a given exposure time. Schmidt cameras are used in many important fields of astronomical research, including some astrometric programmes, although their construction tends to limit the precision with which star places can be determined with them.

In recent years a new type of astrograph has been evolved—the large astrometric reflector. Specifically designed for programmes involving positional observations of great accuracy, this type of instrument will clearly become a basic astrometric tool of the future. The most notable example is the pioneering 61-inch reflector developed for the U.S. Naval Observatory and erected at its out-station in Flagstaff, Arizona. Many new devices and techniques are used with this instrument, which is already making important contributions to positional astronomy and will undoubtedly stimulate the construction of a new generation of astrographic telescopes.

Conclusion

In this article I have given only a very brief outline of the broad and complex field of positional astronomy; I hope that I have at least given some idea of its importance and of the rôle it plays in contemporary astronomical research. I hope that I have also shown that it is a field in which remarkable technical innovations have been made throughout the last century or so, and will continue to be made for many years to come. Both the exciting achievements in space and the stimulating work currently being undertaken in observational astrophysics are utterly dependent upon the positional astronomer for their successful continuance.

Acknowledgement—Figure 2 is reproduced from *Encyclopedia of Astronomy* by kind permission of the Hamlyn Group.

Amateur opportunities in Contemporary Lunar Research

W. J. LEATHERBARROW

It is a sad paradox that few amateur lunar observers realize that first-hand investigation of the Moon by orbiting spacecraft and manned landings, rather than rendering amateur work obsolete, has in fact provided it with a powerful research tool with which the amateur may supplement his telescopic observations. Previously, lunar observation had been almost entirely the domain of the telescopist. Close-up photography of the lunar surface has now become an indispensable means of supplementing telescopic observation.

The following suggested lines of amateur research, while demanding little other than a skilled observer, access to a good telescope, and a selection of Orbiter pictures[1], are designed to produce results of lasting value. The transient value of detailed amateur moon-mapping must be a lesson to us all, and future work, both amateur and professional, must be more statistical and analytical in nature.

It is my belief that these lines of investigation are capable of producing results of value at least until the end of the present century, and irrespective of future space developments. It is hoped that this will be apparent from the nature of the work to be described.

Work for the Telescopist

The main advantage of the telescope over existing photographs taken by orbiting spacecraft is its versatility. Orbiter photographs are severely limited by the fact that they show a given area under only one aspect of illumination. Therefore, while

being unsurpassable in their revelation of fine topographical detail, they are of little value in studies of a time-dependent nature. It is on these studies that the telescopist must concentrate.

Project Moonhole is a case in point. By carefully estimating the east-west fraction of a crater that is covered by shadow, and recording the time of the estimate to the nearest minute, the observer has provided all the observational material necessary for measurement of the depth of that crater. Simple trigonometrical reduction does the rest[2]. A list of suitable craters has been published[3], and the observer should attempt to estimate these as often as possible, under all angles of incident solar illumination. Personal error is, of course, inevitable, but it can be greatly reduced if the observer is careful and conscientious. Observations should never be restricted to simple visual estimates —if possible a micrometer should be used, but good results can be obtained without it if the observer *draws* the area under observation, checking the accuracy of his sketch against the telescopic view and measuring the extent of the interior shadow from his drawing only when he is satisfied as to its accuracy and complete objectivity. Observers should also endeavour to secure observation of the *exterior* shadow cast by a crater wall, as this yields additional information about the height of the crater wall above the surrounding terrain.

Closely allied to Project Moonhole, if somewhat more demanding, are *estimates of the angles of lunar slopes*. These estimates require patience, as well as a good amount of observational skill. The observer is required to estimate to the nearest minute the time when all traces of shadow leave a given slope as the sun rises over this slope. Alternatively, estimates may be made of slopes over which the sun is setting by estimating the moment when the first traces of shadow appear on the slope. It is evident that, at these times, the angle of slope will be equal to the altitude of the sun above the area of observation. Once the initial observations have been made, the results can be reduced to produce reasonably accurate slope values.

The main drawback inherent in this work is that the first or last traces of shadow on a slope are bound to be small and, consequently, difficult to detect, even with large telescopes. There is no way around this problem, and we are obliged to resign ourselves to certain inaccuracies in our results, but at least they will be of the right order.

Probably, slope estimates are of greatest value when they are applied to observations of such craters as Bullialdus and Eratosthenes. If we can obtain an accurate profile of such a crater we shall learn much. There is, however, one final point to be borne in mind. It is that these estimates can produce sensible results only when applied to slopes that tend in an east-west direction, and it is worth checking the direction of any slopes selected for observation. If they are not parallel to the lunar equator to within a few degrees, it is safer to leave them alone.

Next we must consider observations of *areas suspected of variability*, and one of the oldest and most observed problems of this nature is that of the variable spots on the floor of the crater Plato. This crater is one of the best-known areas on the whole of the Moon's visible hemisphere, and our knowledge of its topography has been greatly improved by the magnificent pictures sent back by the American Orbiter vehicles. One such picture was reproduced as the Frontispiece of the *Yearbook of Astronomy 1970*. But, despite our detailed knowledge of this vast formation, we are still unable to explain, with any certainty, the changes in interior detail which have been observed since before the turn of the century. More observations, using telescopes of greater aperture than eight inches, are urgently required. Observations may be checked against each other and also against the Orbiter views for evidence of variability. Personally, I feel sure that most of the observed changes in the interior detail of Plato may be ascribed to errors of observation and variable seeing conditions, but there is some evidence for genuine transient phenomena in the Plato area and this may offer an alternative explanation. We need more observations before we can be at all sure. The observer must take care to ensure that he is completely

objective and that he makes his observations only when observing conditions are good.

Another formation suspected of variability of a sort is Eratosthenes, which is prominent on the earth-turned hemisphere of the Moon and will richly repay close telescopic scrutiny. The American astronomer, W. H. Pickering was the first to devote attention to the unpredictable variations in appearance undergone by Eratosthenes during the course of a lunation. His observations of the area, made under all angles of illumination, are very useful indeed, although we must rule out his explanation of the phenomenon as due to gigantic swarms of insects!

Nonetheless, we are unable to give a certain explanation of the variations seen in Eratosthenes, although a recent suggestion by Firsoff[4] that they may be attributed to a temporary, localized atmosphere has much to recommend it. If this is the correct explanation the variations of Eratosthenes must be classified as a form of genuine transient lunar phenomenon. In any case, more observations are urgently needed, and Eratosthenes will make an ideal subject for filter observation.

This leads us on, rather conveniently, to the subject of Transient Lunar Phenomena, or, more simply, T.L.P.s. Much has been heard of these since the observation, by Sartory *et alia*, of an outgassing of some description in the crater Gassendi[6]. This was in April 1966, but previous 'events' had been reported by many earlier observers, including the noted Russian professional Kozyrev.

Sartory's observation was made with a device known as *Moon-Blink*, and all prospective T.L.P. observers are urged to equip themselves with a similar device. Various descriptions of it have been published and the observer is recommended to consult the *Circulars* of the B.A.A. Lunar Section. Basically, all that is required is a device which will permit the rapid alternation of blue and red gelatine filters, so that the observer can see a given region first in blue light and then in red. With this device any active area is revealed as a blinking spot, since, although it is invisible in red, it appears bright in blue.

This description of T.L.P. technique is of necessity superficial, but the literature on the subject is voluminous. The main disadvantage of this work is that it is so open to misuse by incompetent observers, and we have seen many examples of this recently. The technique must be used only by well-trained and experienced observers, otherwise it can cause only harm.

Closely connected with this work is the study of *colour on the Moon*, and this is a field which has been unjustly neglected by amateur astronomers. The observer is here recommended to study an extremely useful chapter in Firsoff's recent book *The Old Moon and the New*[4]. In experienced hands monochromatic filters will reveal many areas of subtle, localized colour, and careful examination and charting of these areas will tell us much about the history and nature of the lunar soil. This work is certainly arduous and is wide open to personal error, but if sufficient experienced observers participate, the results will be well worthwhile.

Probably the most fruitful type of lunar work now open to the amateur is the application of geological knowledge to the formations visible on the surface of the Moon, for it is in such work that we must seek the key to full realization of the forces responsible for the development of lunar surface history. Such work requires not only a sound basis of geological knowledge, but it relies for its results on the accumulation of masses of data concerning the statistics and distribution of various types of lunar surface feature. The value of such data in the hands of a competent theoretician may be seen in Fielder's commendable book *Lunar Geology*[5]. Few professional astronomers are at present engaged upon the accumulation of this necessary data, and the field is wide open to amateur intervention provided that the observer is prepared to be single-minded and has equipped himself with a rudimentary knowledge of geological agents and forces.

Much of the required information may be acquired by the careful and systematic study of lunar distribution, and the programme of work to be described is that drawn up by Fielder

himself when he was Director of the B.A.A. Lunar Section. To put the matter at its simplest, the observer is required to plot on special charts the distribution of various representative types of surface feature. Not only is this work statistically useful, but in prompting the observer to look for *types* of feature, instead of studying given *areas,* it instils in him a more analytical approach to his work, which is certainly a step in the right direction.

Teamwork is absolutely essential for these studies, and all interested observers are recommended to work in conjunction with the B.A.A. Lunar Section, whence they can obtain the necessary charts and fuller instructions than can be given here. Charts for this work must be photographically-based and on a fairly large scale, as accurate positioning is the all-important factor.

Certain features lend themselves particularly well to this plotting work and these are listed below:

(1) Rilles, ridges, and faults. These should be carefully recorded, as they yield useful information about tectonic alignment.

(2) Domes. Many of these are shown on Orbiter pictures, but telescopic examples should also be plotted since we are interested more in the distribution of the larger examples than the discovery of small domes.

(3) Crater-chains, where the components are less than 20 km. in diameter.

(4) Banded craters. High illumination will reveal many examples of band structures within crater rings, and these have not yet been properly charted.

(5) Ghost craters. Close scrutiny of isolated ridges and crater-chains will often reveal hidden ghost craters. Particular attention should be paid to cases of ghosts interrupting, or being interrupted by, more substantial features.

(6) Ghost Maria. Often the boundaries of old or undeveloped maria may be traced in the highland areas, and these should be carefully looked for. Known examples include the Altai

Scarp, which is concentric to the Mare Nectaris, and the ridges and troughs surrounding the Mare Orientale.

(7) Lunar rays. Particular attention should be paid to cases where a ray is interrupted along its course by ridges etc. Accurate drawings should be made of these.

(8) Interlocking craters.

(9) Plateaux. Wargentin is the most famous example, but there are others.

Searches should also be made for cases where there is a discernible difference in level on opposite sides of a wrinkle ridge, or at the junction of two maria. There may be an example of this at the juncture of Mare Serenitatis and Mare Imbrium, but this needs confirmation.

It is obvious that much of this work can be carried out in great detail by means of Orbiter pictures, but there is still a need for observations of the overall picture and the telescope is ideal for this. Comparison of the grid system charts of Firsoff[4] and Fielder[5] will suffice to show that we still do not know the precise distribution of even the major features of the lunar surface.

Accurate statistical work such as this will yield very useful results. The limitations of telescopic observation may be supplemented by careful inspection of available Orbiter pictures, and this deserves further attention.

Work for the Observer equipped with Orbiter pictures

In fact, the amount of possible work offered by the Orbiter results is limited only by the extent of the worker's geological knowledge and the amount of time he has available. There is certainly enough material to keep the average observer busy for many, many years! All prospective investigators should have a rudimentary knowledge of geological forms, and should be able to recognize examples of major geological structures. For the trained geologist, the field is unlimited.

Here it is possible to recommend only a tiny fraction of the total work to be done, but it should suffice to show that the

trained mind can detect a tremendous amount of highly valuable information on available prints.

First, and as we have already seen, the Orbiter results offer a fine extension to the telescopic distributional work, and all individual examples of rilles, ridges, rays, and ghosts etc. should be examined in detail for evidence of relative dating and possible modes of origin. Similarly, it should be possible to plot localized grid systems from individual Orbiter frames. These may later be brought in to the overall distribution revealed by the telescope and earth-based photographs.

The Orbiter frames are particularly useful in the study of ghosts, since the co-incidence of ghost craters with other topographical features yields valuable information about relative ages. My own work along these lines tends to suggest that Fielder[5] is right when he says that ghosts are relatively young features.

Also, we have heard a great deal recently about the suggestion that the sinuous rilles revealed by the Orbiters may be dried-up river beds. They certainly look like river beds, but can we find more definite evidence? I suggest that interested investigators might like to look for indications of *ox-bow lakes*, where a meandering watercourse has taken a short-cut and isolated some of its meanders. One would certainly expect these along rivers that meander as much as the sinuous rilles. It is also useful to study cases where rilles interrupt, or are interrupted by, other features.

It is obviously impossible to go into further details about the numerous other items of investigation open to the lunar observer who has access to Orbiter pictures. The B.A.A. Lunar Section will offer advice to interested observers, and all are recommended to join this body.

Work such as I have described will not lose value within the foreseeable future, and it should continue to produce results of value even when a permanent scientific base is established on the lunar surface. Certainly, it has been tailored to fit the requirements of post-Apollo lunar science and, provided that it is adequately supported by capable investigators, it should go a long

way towards solving many of the outstanding problems of lunar surface history.

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The 1969 Space-probes to Venus and Mars

H. G. MILES

The outstanding event of 1969 was, of course, the landing of American astronauts on the surface of the Moon. Nevertheless, from a space exploration point of view there were two other events which in themselves were major achievements and which resulted in a much improved understanding of our near neighbours in space. These events were the controlled descents through the atmosphere of Venus by the Soviet space-probes *Venus 5* and *Venus 6* and the American Martian probes *Mariner 6* and *Mariner 7*. The information collected from these probes has shown that there are very few similarities between the Earth, Venus, and Mars, and that it is virtually impossible for life as we know it on Earth to exist on either of the two other planets.

Although Venus is the closest planet to the Earth, it was until recently an unknown world, mainly because of its thick cloud cover. It was therefore a natural development that both the United States and the Soviet Union should allocate part of their space programme to the sending of spacecraft to this planet. The first successful probe was the American *Mariner 2*, which made a near approach to the planet on 14 December 1962. The Soviet Union's *Venus 3* made a crash landing on the planet in 1966, and in the following year *Venus 4* achieved a controlled descent through its atmosphere.

It was not so very long ago that astronomers thought that the atmosphere of Venus contained about 10 per cent of carbon dioxide, but the results from *Venus 4* indicated that the figure was more likely to be in the region of 90 per cent. Information

from the same probe also indicated that the surface temperature and pressure were 270°C and 18 atmospheres respectively. These figures were obtained by fitting the recorded values of temperature and pressure obtained during the descent into two theoretical models for the atmosphere, one based on hydrostatic equilibrium and the other on a dynamic model. The American probe *Mariner 5*, which passed near to the planet within a few days of the Russian craft, provided information which conflicted with the Soviet figures, and further analysis of the information from both probes suggested that a much higher value for temperature and pressure might exist on the surface of the planet. The apparent discrepancy between the two sets of information is now thought to have been due to an ambiguous interpretation of the signals relayed back by the probes' radio altimeter, giving rise to two possible values differing by 30–40 kilometres. It is thought that transmissions from *Venus 4* ceased before the capsule reached the surface, the very high atmospheric pressure having caused the case of the probe to collapse, and resulting in a failure of the instruments.

The 1969 probes were therefore designed to withstand much higher loads and to survive deceleration forces up to 450g. This high value was required because of the much higher speed of entry into the atmosphere due to the relative positions of the Earth and Venus. The two probes were more or less identical, each being one metre in diameter and weighing 405 Kg. Each consisted of two separate compartments. One contained the scientific equipment, batteries, and transmitters, and the other the parachute systems. The rate of descent through the atmosphere was increased over that of the earlier probe by decreasing the size of the parachutes. Consequently information on the atmosphere was transmitted for just under one hour compared with ninety-three minutes for *Venus 4*.

The probes entered the atmosphere at a speed of 11·8 km. per second and at an angle of about 65° to the local horizon. After aerodynamic braking, the parachutes opened, and at this point the radio transmitters were turned on. For fifty-three and fifty-

one minutes respectively the probes relayed detailed information on the planet's atmosphere.

The capsules were designed to provide information on the composition of the atmosphere, the temperature, pressure, and density at various points as the probes descended and also to determine the intensity of illumination at various levels. The gas analyzers determined the amount of carbon dioxide and nitrogen, together with oxygen, the inert gases and water vapour at a given point in the atmosphere, and each probe was capable of taking two samples. In the case of *Venus 5* the first analysis was made soon after the opening of the main parachute, when the pressure was about 0·6 atmospheres and the temperature about 25°C. The second occasion occurred at a point where the pressure was about 5 atmospheres and the temperature about 150°C. In the case of *Venus 6*, the corresponding positions were at 1 atmosphere and 60°C and at 10 atmospheres and 225°C. Preliminary analysis shows that the planet's atmosphere contains between 93 and 97 per cent carbon dioxide. Nitrogen and the inert gases account for between 2 and 5 per cent, and the percentage of oxygen does not exceed 0·4. In the higher regions of the atmosphere the amount of water vapour present is less than that required to saturate it. This means that any clouds existing in these regions are not formed of water vapour.

Pressure and temperature measurements were made every forty-five seconds. The figures ranged from 0·5 to 27 atmospheres and temperatures ranged from 25°C to 320°C. Preliminary data shows that the altitudes registered by the radio altimeters differed by 12–16 km. According to the instruments on *Venus 5*, a pressure of 27 atmospheres corresponds to an altitude of 24–26 km.; but according to *Venus 6*, the same pressure corresponds to an altitude of 10–12 km. Since the 27-atmosphere pressure corresponds to the same distance of descent, it may indicate that the surface of the planet is very uneven. The vertical changes in temperature correspond closely with those expected with adiabatic changes. If the vertical changes are extrapolated down to the surface, it suggests pressure in the region of 60 atmospheres

and temperatures of 400°C for *Venus 5*, and 140 atmospheres and 530°C in the case of *Venus 6*. The photoelectric sensors did not register illumination above 0·5 watts per square metre except at one point by *Venus 5*, which gave about twenty-five watts. At the moment it is not known whether this is a real value or a fault.

From the information collected so far, it is obvious that Venus is a truly strange world. Much has been learned during the last few years, but there are many more important questions to be answered. For example, everyone would like to know what the surface is like. Perhaps it will not be too long before we know the answer to this.

Our other planetary neighbour, Mars, is however, an entirely different world. Earth-based telescopes have for many years made detailed maps of its surface features. Nevertheless the smallest feature that can be resolved from the Earth is in the region of 100 km. Photographs taken from probes in the vicinity of the planet would remove this deficiency, and so in 1965 the American probe *Mariner 4* was dispatched to obtain information of the small-scale features. Although only 1 per cent of the planet's surface was photographed, it showed that the Martian surface was not too different from that of the Moon. The resolving power of the system permitted features as small as 3 km. to be identified. The Americans have now followed this up with two far more sophisticated probes, *Mariner 6* and *Mariner 7*, which flew past the planet on 31 July 1969 and 5 August respectively. The former made an equatorial pass, and the latter examined, amongst other areas, the south polar region. Whilst in the vicinity of the planet, they carried out experiments to provide further information on its atmosphere, surface temperature, and pressure as well as surface features. It must be emphasized that the experiments were not designed to detect the possible existence of life, but to ascertain whether the conditions existing there are such that life as we know it could exist.

A brief outline of our knowledge of conditions existing on Mars prior to the summer of 1969 will show the significance of

the experiments placed aboard the *Mariners*. From the Earth, one of the striking features about the planet is that the surface appears to be divided into two main types of terrain. The brighter regions, accounting for about two-thirds of the total surface, are distinctly orange in colour, whilst the darker areas seem to fluctuate in intensity according to the season. The brilliant polar caps were believed to be thin layers of ice or frost; these could be seen to recede in the Martian spring, and it was possible that they were associated with the waves of darkening. Little water vapour had been detected in the Martian atmosphere, which was thought to consist mainly of carbon dioxide. The clouds seen from time to time were thought to be made up of condensed vapour and dust. The latter appear yellow in colour, and can travel at speeds as high as 150 km. per hour. The surprise value for the surface atmospheric pressure (9 mb.), obtained from the occultation experiment of *Mariner 4*, has caused a revision of the techniques to be used for soft landings on the planet in future experiments. A puzzling feature of the atmosphere was the general haze, which although invisible to the naked eye, can be photographed in blue or violet light. It can blot out surface features and then clear quite suddenly. Some Earthbound observers have recorded straight-line markings, the so-called Martian canals. Whether or not they exist, and if they do, whether as continual features or as a discontinuous series of features, could be solved by high resolution photography.

It may be recalled that the earlier *Mariner 4* sent back pictures built up from a 200 line scan. Each line was divided into 200 elements with each element consisting of a shade of grey, graded from 0 white to 64 black. The recent *Mariners* produced pictures built up in a similar way, except that there were 704 lines and 924 elements in each line. With an increase to 256 shades from white to black, it was possible to obtain pictures in far greater detail. The mode of transmission of the information back to Earth was complex, using both analogue and digital techniques. There were two independent camera systems. Camera A consisted of a wide angle lens (f/5·2) with a field of 18°. Exposures

were made through a rotating filter wheel containing filters in a sequence red, green, blue, green, and red. Camera B, on the other hand, had a much higher resolution. It consisted of a f/2·5 Schmidt-Cassegrainian system of focal length 508 mm., giving a field of view of about 1·8°. All photographs from this camera were taken through a yellow (minus blue) filter to reduce the effect of haze.

Both cameras were mounted on a platform which could be rotated and tilted to allow for overlap of camera A exposures and for any change of target if required. The picture-taking sequence was divided into two separate periods. The 'far encounter' involved taking photographs with the high resolution B camera, starting about fifty-four hours before closest approach. By this means it was possible to obtain a series of full disk photographs, covering most of the planet as it rotated in front of the approaching spacecraft. The 'near-encounter' involved alternate exposures with the A and B cameras, with an overlap of two consecutive A exposures and the intermediate B exposure recording part of the overlapping area. *Mariner 6* took fifty 'far encounter' and twenty-five 'near encounter' photographs, the latter being centred on the equatorial regions. *Mariner 7* on the other hand, sent back ninety-three 'far encounter' and thirty-three 'near encounter' pictures, covering the south polar cap as well as parts of the low latitude regions. Because of less electronic noise in the circuitry, the photographs from *Mariner 7* were superior to those of the earlier probe. In addition, the B camera of *Mariner 7* gave much higher sensitivity.

The 'far encounter' series from *Mariner 6* showed many of the well-known features seen from the Earth. One interesting aspect was the appearance of the northern edge of the south polar cap. It was well defined, irregular in shape, and craters could be identified quite easily within the cap as well as on the edge. Another feature which immediately caught the eye was the fact that the bright polar cap did not reach the edge of the planet, i.e. there was a very pronounced but uneven limb darkening. *Mariner 7*, still on its way to the planet, was therefore pro-

grammed to give maximum coverage to the south polar region. On changing to the 'near encounter' sequence, the probe sent back a series of detailed pictures of the region along the Martian latitude 15°S, in the vicinity of the bright area Deucalionis Regio, south of Sabæus Sinus. From a distance of only 3,400 km., a resolution of 3 km. was achieved for camera A and 300 metres for the B camera. The preliminary analysis of the 'near encounter' frames showed that craters exist in very large numbers, with hardly any difference between the dark and bright areas. Although craters of all sizes were identified, the size-distribution curve for at least some areas appear to have breaks in it, a feature not shown by similar studies on lunar craters. Another difference which was immediately apparent was the much lower percentage of craters having central peaks.

The quality of the photographs relayed back by *Mariner 6* was a tribute to all the scientists and technologists associated with the projects. The fact that *Mariner 7* gave a repeat performance within one week with even better quality pictures has made the event one of the highlights of America's space research. The 'far encounter' photographs showed quite clearly a 350 km.-diameter crater in the Elysium region. Another prominent feature was Nix Olympica, a crater with a diameter of 500 km. The first of the 'near encounter' frames covered the Sinus Meridiani region, and then the target was switched to the south polar cap. Within the cap could be seen many craters, even in the vicinity of the pole itself. At the edge of the cap, the south-facing slopes of the craters were snow-covered, whilst the north-facing slopes appeared dark. After swing across the polar cap, the cameras returned to the low latitudes again, this time in the region of Hellespontus and Hellas. Although craters appeared in large numbers in the area of Hellespontus, very few could be identified within Hellas.

Preliminary results from both probes show that the Martian surface consists of three main types. Of the 20 per cent of the surface photographed during the 'near encounters', most of this was a relatively smooth but cratered surface, covering both the

bright and dark areas. There are however well defined yet irregular shaped regions consisting of a jumbled mass of ridges, practically free of craters. One such area covers over 1 million square kilometres. The third type of terrain is that similar to Hellas, flat, featureless, more or less devoid of craters. Some of the features seem to alter their appearance by changing contrast as the Martian day progresses. The 'blue clouds', thought to be responsible for the masking of surface features when observed through a blue filter from Earth-based observatories, do not in fact exist. The apparent masking is therefore due to some as yet unknown process. The pictures of the Martian limb taken by *Mariner 7* show a horizontal layer of scattered light in the atmosphere. This scattering varies from place to place and in height from the surface of the planet.

The occultation experiment with *Mariner 6* was very rewarding. This involved studying the behaviour of the transmitted signal as the probe passed behind the planet. Analysis showed that at the point of disappearance, in the vicinity of Meridiani Sinus, the surface pressure was 6·5 millibars and the temperature −13°C. At the point of emergence (Lat 79°N Long 274°) the pressure and temperature were 6·2 mb. and −113°C respectively. The figures for *Mariner 7* were not so reliable, because of uncertainties in the position at the moments of disappearance and emergence. At disappearance (near Hellespontica Depressio) the recorded pressure was only 3·2 mb., suggesting that in that area, the surface is much higher than the normal level.

The U/V spectrometers, designed to provide information on the composition of the Martian atmosphere, detected the presence of atomic hydrogen and oxygen in the upper regions, and carbon dioxide and monoxide in the lower layers. Nitrogen was not detected. *Mariner 7* recorded a sudden increase in the U/V intensity as the scanner passed from a bright area to the polar cap, thus indicating that U/V radiation can penetrate down the planet's surface. The I/R spectrometer showed that the amount of carbon dioxide varied over the surface, and that there were also considerable variations in temperature, with the dark

areas being generally warmer than the bright areas. The presence of ice and carbon monoxide was recorded.

The infra-red radiometer, designed to measure temperatures on the planet's surface, confirmed that the dark areas were warmer than the bright regions. Noon temperatures at 15°S latitude seem to be in the region of 16°C, dropping to −73°C at night. In the polar cap, temperatures of −110°C were recorded, a value which would permit carbon dioxide to exist in a solid state under Martian conditions. This suggests that the polar caps are composed of solid carbon dioxide.

It must be emphasized that the information released so far is of a preliminary nature, and many more interesting facts will emerge when the data has been analyzed fully. The above results do show, however, that Mars is not the friendly planet it was once thought to be.

Without doubt further probes are going to be sent to Venus and Mars. The times at which spacecraft can be sent to the planets depend mainly on the rocket power available, the most economical times being governed by the relative positions of the Earth and the planet in question. For Venus, these 'windows' occur every nineteen months and for Mars every twenty-six months. The next period for Venus occurs about August 1970 and for Mars about May 1971. The Americans have already announced that on this occasion two *Mariners* will be sent to orbit the planet for three months; and during the next 'window', probes capable of soft landing on the planet are planned.

Spacecraft to Venus and Mars

	Country	*Launch date*	*Notes*
Venus			
Venus 1	U.S.S.R.	12 Feb. 1961	Radio contact lost when 7·5 million km. from Earth. Passed 100,000 km. from Venus 19–21 May 1961.
Mariner 2	U.S.A.	27 Aug. 1962	Passed 41,000 km. behind Venus on 14 Dec. 1962.
Zond 1	U.S.S.R.	2 Apr. 1964	Passed 100,000 km. from Venus in mid-July 1964.
Venus 2	U.S.S.R.	12 Nov. 1965	Passed 24,000 km. from Venus on 27 Feb. 1966.
Venus 3	U.S.S.R.	16 Nov. 1965	Hit Venus on 1 Mar. 1966. Impact 450 km. from centre of visible disc.
Venus 4	U.S.S.R.	12 June 1967	Controlled descent through Venus' atmosphere on 18 Oct. 1967.

	Country	*Launch date*	*Notes*
Mariner 5	U.S.A.	14 June 1967	Passed 4,000 km. behind Venus on 19 Oct. 1967.
Venus 5	U.S.S.R.	5 Jan. 1969	Controlled descent through atmosphere on 16 May 1969.
Venus 6	U.S.S.R.	10 Jan. 1969	Controlled descent through atmosphere on 17 May 1969.
Mars			
Mars 1	U.S.S.R.	1 Nov. 1962	Lost Earth lock at a distance of 115 million km. Passed 193,000 km. from Mars on 19 June 1963.
Mariner 4	U.S.A.	28 Nov. 1964	Passed 9,850 km. behind Mars on 15 July 1965.
Zond 2	U.S.S.R.	30 Nov. 1964	Passed 1,500 km. from Mars on 6 Aug. 1965.
Mariner 6	U.S.A.	24 Feb. 1969	Passed by Mars at a distance of 3,400 km. on 31 July 1969.
Mariner 7	U.S.A.	27 Mar. 1969	Passed by Mars on 5 Aug. 1969 at a distance of 3,600 km.

Exploring the Outer Planets

IAIN NICOLSON

In a sense, one could say that the exploration of the planets began in 1609, when Galileo Galilei became the first man to turn the telescope on these bodies and place reasonable interpretations on what he saw. Until comparatively recently, the optical telescope and its associated ancillary equipment (such as the spectroscope) remained the only tool available to the astronomer to continue the investigation. The post-war period has seen the development of radio-astronomy, balloon borne, rocket borne, and, more recently, satellite borne instrumentation, each of which has added a new dimension to the understanding of our solar system environment.

Each of the above methods of exploration depends upon information reaching the Earth from the other planets in the form of electromagnetic radiation, and it is a feature of our atmosphere that, broadly speaking, it will only transmit to ground level radiation of certain specific wave-length ranges. The two best known radiation windows are the visible (0·4 to 0·8 microns wave-length, where 1 micron = 1/10,000th of a centimetre) and the radio region (roughly from 1/10th cm. to 100 cm.); however, a certain amount of radiation, particularly in the infra-red (longer than 0·8 microns) region does reach the ground. It is only in the last few years that suitable detectors have been developed to take advantage of these additional windows (see D. A. Allen's article in the 1969 *Yearbook*), largely, it must be said, as a result of military research. With the exception of the field of infra-red astronomy, it would not be far wrong to say that the exploration of the planets by means of earth-based instruments has reached its limit.

Only by placing instruments above the atmosphere can the entire spectrum be made accessible, and full use made of the information reaching us. It is often said that the planets shine only by reflecting light from the Sun, and as far as visible light is concerned this is pretty well the case. However, when one considers, for example, infra-red radiation, a different story emerges. Room temperature objects (i.e. 270°K. to 300°K.) emit radiation with a maximum of about 10 microns; cooler objects emit at longer wave-lengths, hotter objects at shorter wave-lengths. We know that the Sun emits only a small proportion of its radiation at infra-red and longer wave-lengths, and we can work out how much reflected radiation we ought to receive from a planet. To this will be added the radiation appropriate to the planet's temperature, and this can be distinguished. Localized temperature variations can be detected by scanning a planet's disk at longer than visible wave-lengths. This is only one example of the benefits to be derived from making use of regions of the spectrum previously inaccessible.

However, as far as Venus and Mars are concerned, many major advances in our understanding became possible only when Russian and American space-probes were dispatched on close fly-by or soft-landing missions to these planets. The information received in this way not only provided completely new knowledge, but also upturned quite a few preconceived notions. It is apparent that a great deal of information concerning the outer planets of the solar system will be forthcoming when space-probe investigations are undertaken and plans are well advanced for such missions to be flown in the current decade.

The planets Jupiter, Saturn, Uranus, and Neptune form a group known as the Jovian or giant planets, each of which is many times larger and more massive than the Earth, Jupiter, for example, being eleven times the diameter and 317 times the mass of the Earth. In fact Jupiter is considerably more massive than all the other planets in the system put together—even though its mass still only amounts to 1/1000th of that of the Sun—and it has been remarked that the Solar System consists

of the Sun, Jupiter, and débris! The Jovian planets have several features in common. First, although they are much more massive than the earth, they are several times less dense (Saturn has a mean density less than that of water, about 0·7 gm./cc. compared with the Earth's 5·5 gm./cc.); secondly, despite their great size, they rotate on their axes in considerably shorter periods than the Earth, with the result that the velocity of rotation is very high at the equator (about 27,000 m.p.h. in the case of Jupiter). These factors have led to the Jovian planets, in particular Jupiter and Saturn, bulging outwards at the equator and flattening at the poles: the flattening amounting to as much as 11 per cent in the case of Saturn.

Another common feature of these planets is their gaseous structure and composition. It seems likely that none of them has a solid surface in the sense that the terrestrial planets do. By observation and inference, it has been shown that the principal constituent gases making up the giant planets are hydrogen, helium, and hydrides, such as methane and ammonia—the latter two gases being particularly conspicuous in the spectra of the cloud layers which form the atmospheres of these planets. Hydrogen is the principal constituent, and it does seem that the composition of these planets is closely similar to that of the Sun. However, under the conditions of pressure which prevail below the visible surfaces, the hydrogen gas soon becomes solid, and then begins to assume the properties of a metal. Thus the density at the centre of Jupiter, for example, may be as much as 30 gm./cc.

It is not difficult to see why the giant planets should have similar basic compositions to the Sun if two factors are considered. The first point is that the ability of a planet to retain large quantities of light gases such as hydrogen depends upon the escape velocity at its surface: each of the giant planets has a high escape velocity. Secondly, the velocity at which these gas molecules travel in planetary atmospheres is proportional to the square root of the absolute temperature prevailing on these planets: again, the giant planets have low temperatures. Thus, it

has happened that over the thousands of millions of years that the planets have existed, the terrestrial planets, such as the Earth, have lost virtually all their hydrogen, whilst the Jovian planets have retained their quota.

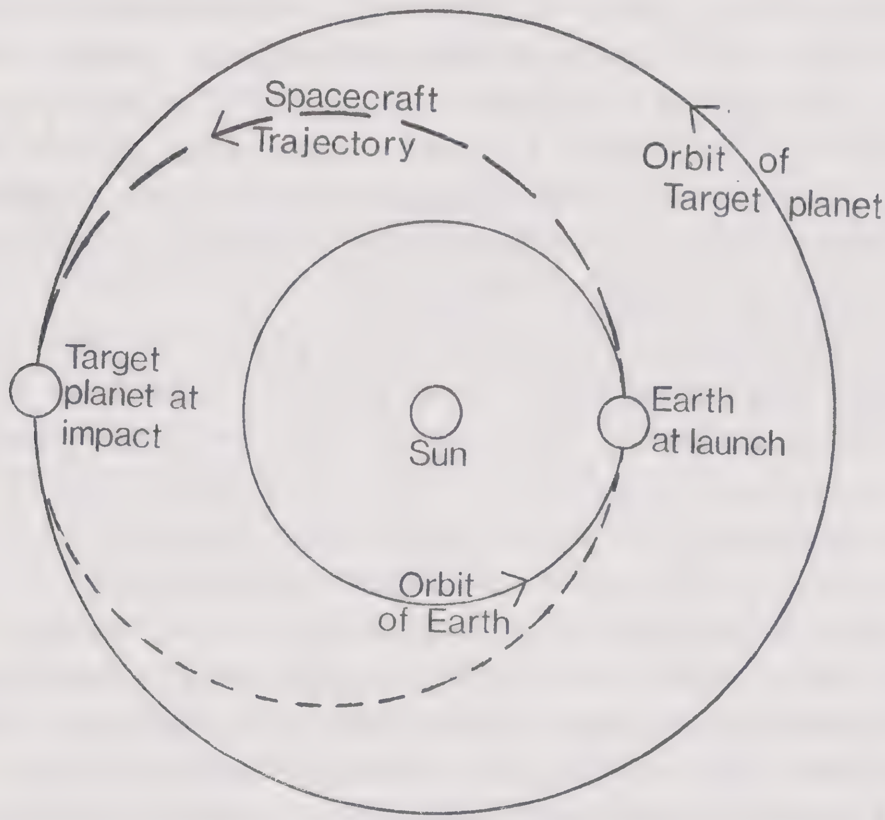

Fig. 1

In general terms, we have summarized the present state of knowledge of the giant planets. The outermost planet, Pluto, seems to be in no way related to the others. For one thing it is a small, solid body, probably without an atmosphere; for another, it moves in a highly eccentric orbit around the sun passing within the orbit of Neptune for part of its path. It may be that Pluto is a captured intruder to the solar system, but at the present time very little is known about it.

Existing rockets have the capability to send space probes to the outer planets, although the time scale involved in such journeys would be quite long. Let us consider ways in which this

could be done. The amount of energy which present-day rockets provide is strictly limited, and it is quite impossible for such a rocket to reach an outer planet by the shortest possible path, i.e., radially away from the Sun. What has to be done is to make use of the Earth's velocity in motion around the Sun (about 30 km./sec.) and launch the spacecraft into a transfer orbit—normally an ellipse. The simplest transfer ellipse, and the one which requires the minimum amount of energy, is the Hohmann ellipse, illustrated in fig. 1. The spacecraft is accelerated up to a velocity in excess of Earth escape velocity (11 km./sec.) and launched in the same direction as the Earth is moving, so that the velocity of the Earth is added to the velocity the spacecraft possesses after escape from the Earth. The craft then coasts in an elliptical trajectory around the Sun which just grazes the orbit of the target planet after half a heliocentric orbit. In other words, the perihelion of the Hohmann ellipse equals the distance from the Sun to the Earth, and the aphelion equals the distance from the Sun to the target planet.

Although the Hohmann ellipse requires the minimum amount of energy, it has the disadvantage that long flight times are necessary—even to reach Mars can take well over 250 days. For unmanned probes this is not too great a disadvantage, but for manned missions where life support systems must be carried, the problem could be quite serious. In practice, a spacecraft is usually launched with a higher velocity at an angle to the Earth's direction of motion, and enters a more eccentric orbit round the Sun with aphelion beyond the target planet and perihelion closer to the Sun than the Earth. Shorter flight times are accomplished at the cost of extra fuel (see fig. 2). For a fly-by mission, the only energy required is that necessary to place the spacecraft in the appropriate orbit, but if a soft landing is to be attempted, sufficient fuel must be carried to match velocities with the target planet, and to brake the craft as it descends to the surface.

In this way The United States hopes to launch a space probe to fly-by Jupiter in 1973—budget cuts permitting. The space-

craft will be a small one—a modified Pioneer vehicle, the principal experiment being to determine the nature and magnitude of Jupiter's magnetic field, and help to elucidate the problem of Jupiter's radio emission. However, the prospects for exploring the outer planets are really exciting in the later part of the present decade, when the planets Jupiter, Saturn, Uranus and

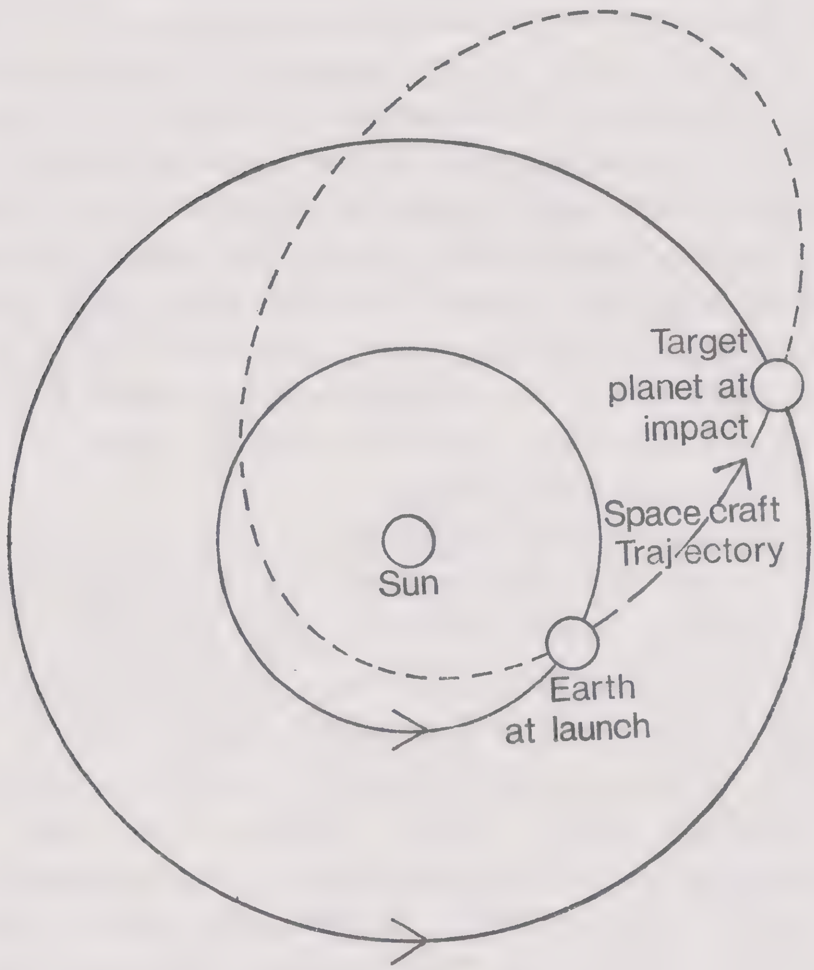

Fig. 2

Neptune will be aligned in such a way that a spacecraft could be launched on a path which would take past all four of them. Not only would all four be examined, but the total time of flight would be considerably less than that required to reach Neptune alone—a reduction from thirty years to nine would be quite possible (see fig. 3).

This is made possible by using a technique known as 'inter-planetary billiards' whereby the spacecraft picks up extra energy from the gravitational fields of the planets it passes. Consider the case of Jupiter. As the spacecraft approaches Jupiter, the gravitational attraction of the planet accelerates it. If Jupiter were stationary, then as the craft passed Jupiter and began to

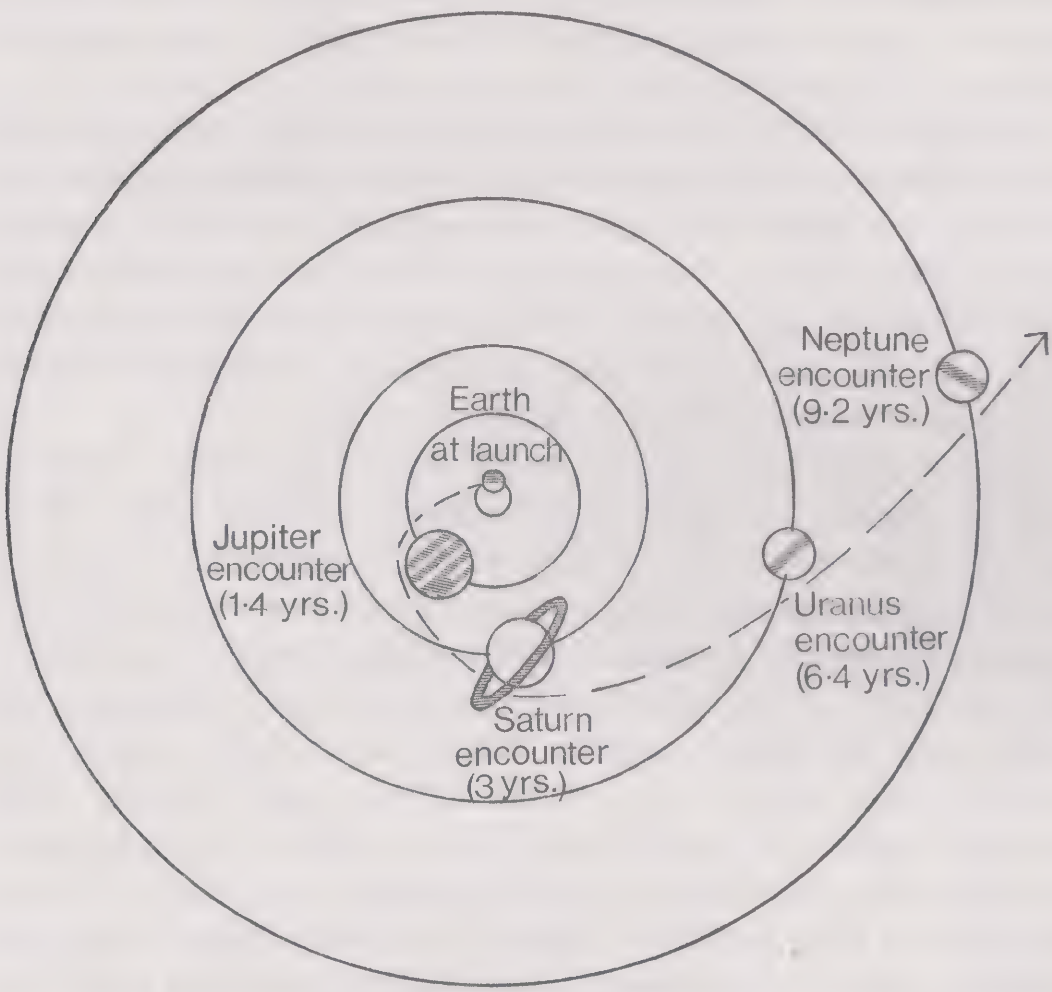

Fig. 3

move away, it would lose this extra speed again: however, Jupiter is moving in its orbit at about 13 km./sec. and this produces a permanent change in the speed and direction of flight of the space-probe. It appears that the craft has picked up extra energy for nothing, but in practice, Jupiter will lose precisely the same amount of energy as the spacecraft gains. By

utilizing this principle at each of the planets, the Grand Tour is made possible. The mission will not require particularly large rockets: even the *Atlas-Centaur* (a mere 200 tons at a launch) could launch a small package. The *Titan 3C* or *Saturn 1B* would be capable of sending useful payloads, whilst the giant *Saturn 5* could send a highly sophisticated probe on an exploration of the giant planets. It must be said, though, that the chances that a *Saturn 5* will be made available for the mission are extremely slight.

It is quite likely that the United States will undertake the Grand Tour in a slightly different fashion, splitting it into two missions—a Jupiter, Uranus, Neptune flight, and a Jupiter, Saturn, Pluto flight. The presence of Saturn's rings makes orbit calculation difficult, and in any case doing the mission this way allows all the outer planets to be taken in. Launchings should take place between 1977 and 1980.

Future exploration of the outer planets probably lies with different types of rockets to the present chemical ones, which are far from ideal for missions of this nature. The chemical rocket must use a very large amount of fuel in a matter of a few minutes to send its payload beyond escape velocity to coast for the remainder of its journey. The limiting factor is the velocity which the hot gases escaping from the rocket's combustion chamber can attain—the exhaust velocity—and existing fuels can only achieve a few km./sec. The ion rocket, which operates by accelerating electrically charged particles, can attain exhaust velocities at least ten times higher. The disadvantage of the ion rocket is that it can accelerate only slowly, albeit for very long periods of time, and is not really capable of escaping from the Earth under its own power. The future deep space rocket is likely to be launched into earth orbit by means of a conventional chemical rocket, and only then will the ion rocket be brought into action to accelerate the spacecraft slowly but steadily to very high velocities—150,000 km./hr. could readily be attained allowing flight times to be shortened. Greater payloads could be carried, too, and it may be possible in the future

to carry out entire missions under powered flight, instead of coasting ballistically as at present.

The nuclear rocket system NERVA is at an advanced testing stage now, and it is just possible that it may be incorporated into the 1970s Grand Tour, suggesting the exciting possibility that a sufficiently high payload may be launched to permit small packages to be dropped off into the atmosphere of the planets as the main craft flies by.

The Grand Tour mission should elucidate many of the problems associated with the outer planets, providing better information on magnetic fields, existence of radiation belts, temperatures, densities, etc., and sending back detailed television pictures. Dr Pickering, of the Jet Propulsion Laboratory in Pasadena, expects to get back better T.V. pictures from Pluto than *Mariner 4* sent from Mars. This is the measure of recent developments in communication techniques. Investigation of the outer planets is moving into the stage of direct exploration, and one of the most interesting coincidences is that, although suitable alignments of the outer planets to permit a Grand Tour mission occur only once in about 180 years, the present alignment should happen just when technology is sufficiently advanced to take advantage of it.

Astronomy and Philosophy

HENRY BRINTON

Astronomy had its beginnings as the handmaiden of fortune telling. The association is not hard to see. From observing that certain celestial events were followed faithfully by other terrestrial ones, it was not an unnatural transition to suppose that the one caused the other. Strictly speaking, and given proper refinements, the whole of modern science is based upon a similar philosophical assumption. In strict logic, there is no reason to suppose that the Sun will rise to-morrow! The so-called laws of nature are nothing more than a codification of those events which experience shows seem always to follow other events. The laws of cause and effect are in the nature of an act of faith. Indeed, it is even doubted whether they necessarily apply to microcosmic events at all.

For a long time after the Babylonian and Egyptian periods, astronomy could be divided into two distinct parts. There was that branch of the subject which was the basis for a crude form of navigation, which only took on any very scientific form at the time of the Renaissance. The second branch was the forum for the exercise of curiosity and inductive logic. The Greeks, in particular, were given to abstract speculation, and sought, with more success than might have been expected, to understand the basic processes of nature by a process of pure reason. Attic Greece saw the heyday of philosophical astronomy. If the process led to some blind alleys, as, for instance, the belief that anything celestial must be perfect and that the circle was the perfect figure in which the heavenly bodies must of necessity move, it did also lead to some surprisingly shrewd guesses. There were also some beautifully reasoned conclusions, for

instance the one which calculated the relative distances of the Sun and Moon.

For some time during and after the 17th century, when agnosticism became respectable, astronomy entered into a long period of ever-improving observational methods and instruments, without any great concern for philosophical implications. It was the 19th century, when Darwin threw his oversized biological wrench into the nicely-ordered works of the religious establishment, which provoked an outburst of atheism and scientific curiosity.

It was also during the 19th century that astronomy began to impinge heavily upon fundamental physics, always a fruitful field for epistomological and metaphysical exploration. Starting with a period when gross materialism seemed to be carrying all before it, it was a combination of physics and astronomy which by degrees made the cruder forms of materialism less and less credible. Even when it was possible to argue that all material phenomena could be explained in terms of the collisions of small hard particles, there was always the still, small voice to inquire: 'Including our perception of the small hard particles?'

At that time, the contribution of astronomy was more subjective; indeed, it might almost be called obscurantist. To look at the heavens through a great telescope was to be lost in awe. The very vastness of the universe, as boundary after boundary crumbled, and man's imagination soared into the unutterably remote and lonely reaches of an ever-expanding space, induced a mood of wonder and humility. It was not a scientific state of mind; but it was a compelling one.

With the 20th century, the mood has developed yet further. 'The small, hard particles' have vanished, resolving into insubstantial abstractions of a form only to be understood in terms of mathematics. It became more and more meaningless to inquire of what an electron or a proton was composed, until logical positivism was born as a school of philosophy to qualify the questions as utterly meaningless.

As the science of physics progresses at the present time, and

few times have been more fruitful or exciting, astronomy has come to play a larger and larger part. The quasar, the pulsar, and the neutron star, to mention only a few of the puzzles which have come to perplex and stimulate the imagination, bring with them doubts about our knowledge of the fundamental properties of matter. Physics becomes daily more challenging to the capacity of man for daring and imagination.

But it is in two other fields that astronomy has thrown a gauntlet to the philosopher rather than the scientist. Cosmology opens up a wide range of familiar problems in a new guise. When Professor Ryle delivered his address at the Royal Astronomical Society, ending with a claim that the Steady State Theory could not stand, the London evening papers devoted the whole of their front pages to the somewhat fanciful statement that scientists had proved the existence of God! This crude statement is perhaps ridiculous; but it is true that the Big Bang Theory does, at first sight, appear to postulate a prime mover. Some may feel that there are alternatives—perhaps the postulate of the pulsating Universe. Even if, at the moment of writing, there are theoretical objections to such a theory, most of us would feel that fresh progress will produce some answer, still possible to reconcile with some form of less crude materialism. However that may be, most of us would also feel that the older forms of materialism have vanished for ever. Beyond that, surely no one can doubt that cosmology does stimulate a popular philosophical curiosity on a scale hitherto unknown.

In one other way, astronomy has provoked widespread philosophical speculation. In the main it is where we enter into space-travel that the interest is most wide-spread. The mere fact that man has, for the first time in his long history, burst out from the constraining bonds of our local gravitational field, and set his foot upon another world, can hardly fail to send thoughts soaring still further, and to provoke questions about other possible sentient beings in our vast and boundless cosmos.

Whichever way we individually would answer the sixty-four dollar question, whether we believe that we are unique, or

merely one among myriads of other intelligent races in the universe, we are faced with a matter of awe. On the one hand, it would be both inspiring and incredible if among the millions upon millions of stars, there were no other inhabited planet. Such a belief might recreate the megalomanias of an earlier age, which saw the whole of creation as a mere setting for mankind, and recreate it on a vaster scale. On the other hand, though we might be humbled by the thought of the commonplace nature of life, we could hardly fail to be stimulated by the excitement of the thought that, one day, surely, we should be in touch with other beings and other ways of life and thought.

Amid all the speculation, and so far it is mere philosophical speculation engendered by the progress of astronomy and technology, there is one sobering and encouraging thought. A great deal is made in the popular media of how we would communicate our ideas to some other civilized beings if we come into touch with them. Fortunately, a little thought will show that the boot would be on the other foot. Mere reflection will show that, if there are other inhabited worlds, the overwhelming probability is that they will be so immeasurably in advance of our own development that it will be they who teach, and we who learn.

Of one thing only we may be sure about ourselves. It is that, at the moment, mankind appears bent upon his own destruction. Our capacity for gaining knowledge of the universe in which we live has wholly outstripped our knowledge about how our emotions work, or our ability to control our behaviour.

Plato, the greatest of all philosophers, saw a future in which the hope lay in the philosopher king. A more modern version would be a people who had become philosophers as well as scientists. At times, astronomy has seemed the most practically useless, or, one might say, the purest, of the sciences. At the moment it looks as though it might provide a fall-out benefit, of value beyond our dreaming. Man may come to see himself as he is.

Recent Developments in Astronomy

PATRICK MOORE

Just as 1969 will always be remembered as 'the Year of the Moon', so 1970 will be recalled as the year of the first space-rescue. The near-disaster of Apollo 13 is still fresh in most people's minds, and there is no point in describing it in detail here; suffice to say that on the outward journey to the Moon there was a sudden, violent explosion in the service module, which put the main power supplies out of action with devastating permanence. (The trouble was not due to a meteorite impact, as was suggested at first.) The lunar landing in the crater area of Fra Mauro was abandoned, and everything was concentrated upon rescuing the three astronauts: James Lovell, Fred Haise, and Jack Swigert, who had come in as a last-minute replacement when Commander Mattingly, the scheduled crew member, was found to have been exposed to German measles.

By miracles of improvisation, together with quite amazing skill and courage on the part of the astronauts, potential tragedy was turned into triumph. Using the power-reserves in the lunar module, Apollo 13 was brought safely home. There were all manner of complications; for instance, the air inside the cabin had to be purified, and Lovell and his companions built the necessary equipment out of articles such as urine bags and old socks! The slightest flagging either by the crew or by the technicians at N.A.S.A. would have been fatal. One very encouraging sign was that for a brief spell, scientists of all nations seemed to be united. Messages of goodwill came from over almost the entire globe. (Only China did not comment. Shortly afterwards, Chairman Mao joined the Space Club, and the first Chinese artificial satellite entered orbit, broadcasting some Oriental music.)

Before Apollo 13 set out, public interest was much less than had been the case with either Apollos 11 or 12. In fact, people were beginning to become blasé about the whole venture. Matters now are very different. At the time of writing, Apollo 14 is scheduled to be launched in December 1970, again bound for Fra Mauro, and to be commanded by Alan Shepard, America's first space-man. But there are to be modifications in design; Apollo 13 has taught N.A.S.A. some hard lessons.

Meanwhile, analyses of the samples brought home by Apollos 11 and 12 have continued. It may be true to say that the work has raised as many problems as it has solved. Certainly the lunar rocks are volcanic, and there are glassy particles in them; they are extremely old, possibly almost as old as the Earth (between 4,000 and 5,000 million years); there is no evidence of meteoritic material, and as yet no tektites have been found. Equally interesting was the Apollo 13 experiment of crashing the original launching rocket on to the Moon. The vibrations set up were recorded by the seismograph left behind by Conrad and Bean in November 1969, and these vibrations went on for almost three hours. According to one theory, which has been strongly challenged, the Moon has two hard, rocky layers separated by less rigid material, making what may be termed a volcanic sandwich. This may or may not be true; future expeditions should be able to find out.

The Mars and Venus probes are dealt with by Howard Miles elsewhere in this *Yearbook*, and I can do no more than refer *en passant* to the proposed Mercury and Jupiter probes of the 1972–3 period. Neither can I dwell on the latest experiments with artificial satellites, mainly by the Russians. Instead, I must turn to what we may still call 'pure' astronomy.

One interesting visitor of early 1970 was Bennett's Comet, discovered in the previous autumn by the South African amateur astronomer of that name. It showed to its best advantage in the southern hemisphere, but when it rose above the British horizon it was still bright enough to be really conspicuous; moreover, it had a long tail. Undoubtedly it was the finest comet for many years. Of equal scientific interest was Comet Tago-Sato-Kosaka,

which was under observation at the same time. It was not so bright, but it was studied by instruments in the automatic satellite known as O.A.O.2 (Orbiting Astronomical Observatory), and was found to be surrounded by a huge cloud of hydrogen as large as the Sun! Whether other comets have comparable hydrogen envelopes is not yet certain; but by any standards, the revelation was important to Solar System theorists. Its full significance may not be appreciated even yet.

Beyond the Solar System we come to the stellar universe; and here attention during 1970 was concentrated on objects such as X-ray sources, pulsars, and quasars. Bowyer, Lampton, and Mack, of the University of California, discovered that the famous radio source known as Centaurus A is emitting twice as much energy in the form of X-rays as it is doing in the radio range. Other extra-galactic X-ray sources are the curious galaxy M.87 and the quasar 3C–273.

Centaurus A is about 12,000,000 light-years away. It is remarkable in many ways; formerly it was believed to be made up of two galaxies in collision, but this attractive theory has long since been given up, and we have to admit that we are still uncertain why it is so powerful a radio source. The X-ray developments heighten the mystery still further, and we can hardly hope that the answer will be found as early as 1971.

It cannot be said that any fundamental advance has been made in quaser research; so far as pulsars are concerned, the general view is that neutron stars are responsible. They may represent the very last stages in the active life of a star. One has been identified optically as a faint, flashing point in the Crab Nebula, which is of course a supernova remnant, and also emits radio waves and X-rays. Quasers and pulsars were much to the fore during discussions at the meeting of the International Astronomical Union, which took place in August 1970, and which was held in England for the first time in many years.

On a rather different tack, a most important development came from Edinburgh University. This was GALAXY, a 'measuring machine' for studying exposed Schmidt plates. A Schmidt tele-

scope can photograph a very wide field, and previously there was so much information to be extracted that progress was painfully slow. GALAXY can obtain the information automatically at a high speed, and will do a great deal to increase the rate of growth of knowledge. This is a purely British development; the main pioneer work was carried out by Professor Peter Fellgett, formerly at Edinburgh and now at the University of Reading.

All in all, the period between mid 1969 and mid 1970 has been one of the most fruitful of recent times. Perhaps the coming months will be even more exciting. We are learning more about the universe every day, and the time when astronomy was widely regarded as a static science is long past.

PART THREE

For Stellar Observers

Test Objects

PATRICK MOORE

How good is your telescope—and how keen are your eyes? These are questions which may not be as easy to answer as might be thought. Moreover, so far as telescopes are concerned, theory and practice do not always agree, because there are so many uncertain and highly variable factors to be taken into account.

There are various features which are on the borderline of naked-eye visibility. Anyone with really keen sight can see the globular cluster M.13 Herculis under good conditions, but it is extremely doubtful whether it could be detected without prior knowledge of its position. (And remember that Tycho Brahe, the supreme observer of pre-telescopic days, completely overlooked the Great Spiral in Andromeda, M.31, which is decidedly brighter than M.13.) It has been claimed that M.33, the Triangulum Spiral, has been seen with the naked eye; this may well be so, but it is quite beyond most people. The average number of stars to be seen in the Pleiades without optical aid, under good conditions, is seven; but the record seems to be reliably held by the last-century German observer, E. Heis, whose total score was nineteen. On a rather different subject, there are the phases of Venus, which are very much on the optical brink. There is still serious controversy as to whether or not they are detectable, but to enter into this would take many pages, and the interested reader is referred to the articles and correspondence in 1969–70 editions of the quarterly magazine *Astronomy Today.*

Let us turn, then, to optical instruments. Immediately all the doubtful cases listed above come into clear view (including the

phases of Venus). Yet there are still more problems to be borne in mind when we come to telescopes. The state of the sky is all-important; an observer who lives in London may be well satisfied if he can see stars down to the fourth magnitude without using a telescope, while his more fortunate colleague in the country would be very cynical about a night where he could not be certain about stars of below magnitude 5.

Many sets of figures for limiting magnitudes have been given, and none of them really agree. The list given here is definitely open to challenge, but at least it will serve as a general guide. The limiting magnitudes are:

For a 2-in. telescope:	10·5	
3-in.	11·4	
4-in.	12·0	assuming excellent optics and
6-in.	12·9	good conditions of
8-in.	13·5	observation.
10-in.	14·0	
12-in.	14·4	

Undoubtedly some variable star observers will claim that they can reach down below these limits, and I would not question this: my only comment is that they must be very keen-sighted. The long-period variable R Cygni drops down to 14·2 at minimum (perhaps slightly fainter at some cycles) and I can follow it with my 12½-in., but when it is at its dimmest it is not easy, and neither are its comparable comparison stars. But the figures given here show that there are many interesting variables which can be followed throughout with small telescopes, and it is worth while taking a careful list from those stars given in the Appendix (page 179). R. Leonis, for instance, is alwayss within the range a 3-in. telescope. For most of the time the fascinating irregular R Coronæ Borealis is a binocular object, but at a deep minimum it can fall to magnitude 15, so that my reflector is unable to show it. (R Coronæ went through a very shallow minimum in 1969. Whether it will have 'performed' in a spectacular matter by the time that these words appear in print remains to be seen.

Its magnitude at the start of 1970 was the conventional 6.) There are some stars, too, which are worth following even though they are inconveniently faint. SS Cygni is usually of magnitude 12, but its outbursts take it up to 8·4, well within the range of a 2-in. telescope—though admittedly only a few of the accepted comparison stars are visible, making the field rather difficult to identify from the point of view of an observer who is used to a larger aperture.

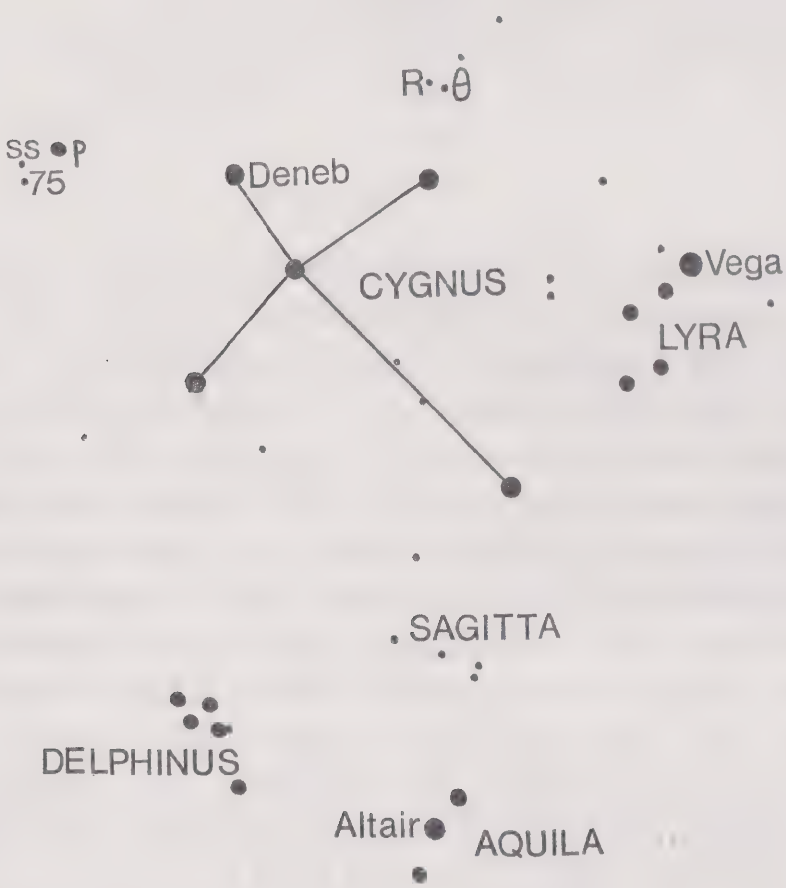

Fig. 1

However, as test objects, variable stars are unsatisfactory, if only because many of them are red while the comparison stars are not. It is much better to check by using double stars, either optical or binary; in most cases, of course, the systems will be of the binary type. Again there are differences of opinion about the minimum separation obtainable. The figures I give below

are based on experience rather than theory, and again they are open to challenge. It is assumed that the two components of the double are of equal brilliancy and of about magnitude 6. Where the components are unequal, the difficulties of separation will be enhanced.

A 2-in. telescope should separate a 6-mag. equal pair of separation 2·5″.

A 3-in.	will have	a limit	of	1·8″.
A 4-in.	,,	,,	,,	1·3″.
A 6-in.	,,	,,	,,	0·8″.
An 8-in.	,,	,,	,,	0·6″.
A 10-in.	,,	,,	,,	0·5″.
A 12-in.	,,	,,	,,	0·4″.

The classic case of an unequal double is that of Sirius. The Dog-Star itself is, of course, the brightest star in the sky: magnitude –1·4. The magnitude of the Companion is 8·6, and the separation can attain almost 10″. As the tables show, a 2-in. telescope can easily show a star of magnitude 8·6, and separate an equal pair much closer than 10″—but anyone who dreams of seeing the Companion of Sirius with a 2-in. telescope is doomed to a disappointment! It has been seen with a 6-in. under excellent conditions, but I very much doubt if this could ever be done from Britain or the northern United States. I am open to conviction, but I do not know of any reliable case. A larger aperture is needed. (There is something of a parallel with Jupiter's Galilean satellites, which would be very easy naked-eye objects but for the glare of Jupiter itself.)

There are a few wide doubles with equal components which afford a great deal of satisfaction to the owner of an inferior telescope! Theta Serpentis is one; each component is of magnitude 4·5, and the separation is 22·6″. Another is Gamma Arietis (4·8 and 4·8, 8·2″). At the moment Gamma Virginis is another easy double for any astronomical telescope, as the components, both of magnitude 3·6, are 5″ apart; but they are closing up, and by the end of the century Gamma Virginis will be a very

difficult pair. Castor, in Gemini, is another binary which used to be much easier than it is now. The components are of magnitude 2 and 2·9, and as the separation is only 2·2″ I find that even with a 3-in, reflector, fairly good conditions are needed.

Fig. 2

Of course, the best example of an easy unequal double is Beta Cygni, or Albireo. To me, this is the most magnificent pair in the sky. The magnitudes are 3 and 5·3, the separation 34·6″, and the colours golden-yellow and green. Any astronomical telescope incapable of showing both components should be rejected out of hand. But so far as real tests are concerned, the following pairs are widely used:

2-in. telescope	Magnitudes	Separation	Pos. Angle
Gamma Leonis	2·3, 3·5	4·3″	122°
Epsilon Boötis	2·4, 5·0	2·8	334
Polaris	2·0, 8·9	18·3	217
Delta Geminorum	3·2, 8·2	6·7	211

3-in. telescope			
Eta Draconis	3·0, 8·0	6·0″	142°
Epsilon Arietis	5·3, 5·6	1·8	208
Theta Virginis	4·0, 9·0	7·2	343
Beta Serpentis (very easy test)	3, 9·2	30·8	265
4-in. telescope			
Theta Aurigæ	2·7, 7·2	2·8″	332°
Eta Orionis	3·8, 4·8	1·4	079
Delta Cygni	2·9, 6·4	2·1	240
Iota Ursæ Majoris	3·1, 10·8	7·4	002
5-in. telescope			
Zeta Boötis	4·6, 4·6	1·2″	309°
Omega Leonis	5·9, 6·7	1·0	129

Fig. 3

The list can, of course, be extended. For instance, Alpha² Capricorni (3·8, 11·0; 7·1″) is said to be a test for a 6-inch, though to me it seems a very easy one. On the other hand I always have some difficulty in separating the faint component of Gamma Andromedæ (5·4, 6·6; 0·7″) with my 8½-in. reflector, though officially it is a test for an 8-in. Lambda Cassiopeiæ (5·5, 5·8; 0·6″) is another test for an 8-in.

If you want to check on your telescope, try some of these tests; then refer to the list of doubles on page 180 and examine some of these. But a word of warning may be appropriate. If the telescope is not coming up to expectations, do not condemn it at once. Check on several nights; things are not always as good as they seem in the Earth's air! Then, if the performance is still poor, make sure that everything is properly adjusted; reflectors are very sensitive to mis-alignment of the optics. Also, even if there is something optically wrong, the trouble may lie in the flat or the eyepiece instead of the main mirror; with a refractor, look carefully at the eyepiece before getting at all worried about the object-glass.

Finally, remember that even if your telescope is not the ultimate in perfection, it can still serve you well within its limitation. I have an old 4-in. refractor which makes no pretence of being first-class, and its colour correction is frankly bad; but it has a very reasonable light-grasp, so that I can use it for variable stars which are within its range and which may happen to be behind trees from my observatories—and it also comes in handy for projecting the Sun!

Some Interesting Telescopic Variable Stars

Star	R.A. *h*	*m*	Dec. °	′	*Mag. range*	*Period, days*	*Remarks*
R Andromedæ	0	22	+38	18	6·1–14·9	409	
W Andromedæ	2	14	+44	4	6·7–14·5	397	
R Aquilæ	19	4	+ 8	9	5·7–12·0	300	
R Arietis	2	13	+24	50	7·5–13·7	189	
R Aurigæ	5	13	+53	32	6·7–13·7	459	
R Boötis	14	35	+26	57	6·7–12·8	223	
R Cassiopeiæ	23	56	+51	6	5·5–13·0	431	
T Cassiopeiæ	0	20	+55	31	7·3–12·4	445	
T Cephei	21	9	+68	17	5·4–11·0	390	
Omicron Ceti	2	17	− 3	12	2·0–10·1	331	Mira.
R Coronæ Borealis	15	46	+28	18	5·8–14·8	–	Irregular.
W Coronæ Borealis	16	36	+37	55	7·8–14·3	238	
R Cygni	19	35	+50	5	6·5–14·2	426	
U Cygni	20	18	+47	44	6·7–11·4	465	
W Cygni	21	34	+45	9	5·0– 7·6	131	
SS Cygni	21	41	+43	21	8·2–12·1	–	Irregular.
Chi Cygni	19	49	+32	47	3·3–14·2	407	Near Eta.
R Draconis	16	32	+66	52	6·9–13·0	246	
R Geminorum	7	4	+22	47	6·0–14·0	370	
U Geminorum	7	52	+22	8	8·8–14·4	–	Irregular.
S Herculis	16	50	+15	2	7·0–13·8	307	
U Herculis	16	23	+19	0	7·0–13·4	406	
R Hydræ	13	27	−23	1	4·0–10·0	386	
R Leonis	9	45	+11	40	5·4–10·5	313	Near 18, 19.
X Leonis	9	48	+12	7	12·0–15·1	–	Irregular (U Gem type)
R Leporis	4	57	−14	53	5·9–10·5	432	'Crimson star.'
R Lyncis	6	57	+55	24	7·2–14·0	379	
W Lyræ	18	13	+36	39	7·9–13·0	196	
HR Delphini	20	40	+18	58	3·6– ?	–	Nova, 1967.
Nova Vulpeculæ	19	45	+27	2	4·8– ?	–	Nova, 1968.
U Orionis	5	53	+20	10	5·3–12·6	372	
R Pegasi	23	4	+10	16	7·1–13·8	378	
S Persei	2	19	+58	22	7·9–11·1	810	Semi-regular.
R Scuti	18	45	− 5	46	5·0– 8·4	144	
R Serpentis	15	48	+15	17	5·7–14·4	357	
SU Tauri	5	46	+19	3	9·2–16·0	–	Irregular (R CrB type).
R Ursæ Majoris	10	41	+69	2	6·7–13·4	302	
S Ursæ Majoris	12	42	+61	22	7·4–12·3	226	
T Ursæ Majoris	12	34	+59	46	6·6–13·4	257	
S Virginis	13	30	− 6	56	6·3–13·2	380	
R Vulpeculæ	21	2	+23	38	8·1–12·6	137	

Some Interesting Double Stars

The pairs listed below are well-known objects, and all the primaries are easily visible with the naked eye, so that right ascensions and declinations are not given. Most can be seen with a 3-inch refractor, and all with a 4-inch under good conditions, while quite a number can be separated with smaller telescopes, and a few (such as Alpha Capricorni) with the naked eye. Yet other pairs, such as Mizar-Alcor in Ursa Major and Theta Tauri in the Hyades, are regarded as too wide to be regarded as bona-fide doubles!

Name	*Magnitudes*	*Separation,"*	*Position angle, deg.*	*Remarks*
Gamma Andromedæ	3·0, 5·0	9	060	Yellow, blue. B is again double (0"·4) but needs a larger telescope.
Zeta Aquarii	4·4, 4·6	2·6	291	Becoming more difficult.
Gamma Arietis	4·2, 4·4	8	000	Very easy.
Theta Aurigæ	2·7, 7·2	3	330	Stiff test for 3 in. OG.
Delta Boötis	3·2, 7·4	105	079	Fixed.
Epsilon Boötis	3·0, 6·3	2·8	340	Yellow, blue. Fine pair.
Kappa Boötis	5·1, 7·2	13	237	Easy.
Zeta Cancri	5·6, 6·1	5·6	082	
Iota Cancri	4·4, 6·5	31	307	Easy. Yellow, blue.
Alpha Canum Venat.	3·2, 5·7	20	228	Yellowish, bluish. Easy.
Alpha Capricorni	3·2, 4·2	376	291	Naked-eye pair. Alpha again double.
Eta Cassiopeiæ	3·7, 7·4	11	298	Creamy, bluish. Easy.
Beta Cephei	3·3, 8·0	14	250	
Delta Cephei	var, 7·5	41	192	Very Easy.
Xi Cephei	4·7, 6·5	6	270	Reasonably easy.
Gamma Ceti	3·7, 6·2	3	300	Not too easy.
Zeta Coronæ Borealis	4·0, 4·9	6·3	304	
Delta Corvi	3·0, 8·5	24	212	
Beta Cygni	3·0, 5·3	35	055	Yellow, green, Glorious.
61 Cygni	5·3, 5·9	25	150	
Gamma Delphini	4·0, 5·0	10	265	Yellow, greenish. Easy
Nu Draconis	4·6, 4·6	62	312	Naked-eye pair.
Alpha Geminorum	2·0, 2·8	2	151	Castor. Becoming easier.
Delta Geminorum	3·2, 8·2	6·5	120	
Alpha Herculis	var, 6·1	4·5	110	Red, green
Delta Herculis	3·0, 7·5	11	208	Optical double.
Zeta Herculis	3·0, 6·5	1·4	300	Fine, rapid binary.
Gamma Leonis	2·6, 3·8	4·3	121	Binary; period 400 years.
Alpha Lyræ	0·0, 10·5	60	180	Vega. Optical; B faint.
Epsilon Lyræ	4·6, 6·3	3	005	Quadruple. Both pairs separable in 3 in. OG.
	4·9, 5·2	2·3	111	
Zeta Lyræ	4·2, 5·5	44	150	Fixed. Easy double
Beta Orionis	0·1, 6·7	9·5	205	Rigel. Can be split with 3 in.
Iota Orionis	3·2, 7·3	11	140	

Name	*Magnitudes*	*Separation,"*	*Position angle, deg.*	*Remarks*
Theta Orionis	6·0, 7·0 7·5, 8·0			The famous Trapezium in M.42.
Sigma Orionis	4·0, 7·0 7·5, 10·0	11·1 12·9	236 085	Quadruple. D is rather faint in small apertures.
Zeta Orionis	1·9, 5·0	3	160	
Eta Persei	4·0, 8·5	8·5	300	Yellow, bluish.
Alpha Piscium	4·3, 5·3	1·9	291	
Alpha Scorpii	0·9, 6·8	3	275	Antares, Red, green.
Nu Scorpii	4·2, 6·5	42	336	
Theta Serpentis	4·1, 4·1	23	103	Very easy.
Alpha Tauri	0·8, 11·2	130	032	Aldebaran. Wide, but B is very faint in small telescopes.
Zeta Ursæ Majoris	2·3, 4·2	14·5	150	Mizar. Very easy. Naked eye pair with Alcor.
Alpha Ursæ Minoris	2·0, 9·0	18·3	217	Polaris. Can be seen with 3 in.
Gamma Virginis	3·6, 3·7	4·8	305	Binary; period 180 yrs. Closing.
Theta Virginis	4·0, 9·0	7	340	Not too easy.

Some Interesting Clusters and Nebulae

Object	R.A. *h*	*m*	Dec. °	′	*Remarks*
M.31 Andromedæ	00	40·7	+41	05	Great Galaxy, visible to naked eye.
H.VIII 78 Cassiopeiæ	00	41·3	+61	36	Fine cluster, between Gamma and Kappa Cassiopeiæ.
M.33 Trianguli	01	31·8	+30	28	Spiral, Difficult with small apertures.
H.VI 33–4 Persei	02	18·3	+56	59	Double cluster; Sword-handle.
M.1 Tauri	05	32·3	+22	00	Crab Nebula, near Zeta Tauri.
M.42 Orionis	05	33·4	−05	24	Great Nebula, Contains the famous Trapezium, Theta Orionis.
M.35 Geminorum	06	06·5	+24	21	Open cluster near Eta Geminorum.
H.VII 2 Monocerotis	06	30·7	+04	53	Open cluster, just visible to naked eye.
M.41 Canis Majoris	06	45·5	−20	42	Open cluster, just visible to naked eye.
M.44 Cancri	08	38	+20	07	Præsepe. Open cluster near Delta Cancri. Visible to naked eye.
M.97 Ursæ Majoris	11	12·6	+55	13	Owl Nebula, diameter 3′. Planetary.
M.3 Canum Venaticorum	13	40·6	+28	34	Bright globular.
M.80 Scorpionis	16	14·9	−22	53	Globular, between Antares and Beta Scorpionis.
M.4 Scorpionis	16	21·5	−26	26	Open cluster close to Antares.
M.13 Herculis	16	40	+36	31	Globular. Just visible to naked eye.
M.92 Herculis	17	16·1	+43	11	Globular. Between Iota and Eta Herculis.
M.7 Scorpionis	17	51·6	−34	48	Fine open cluster. Very low in England.
M.23 Sagittarii	17	54·8	−19	01	Open cluster nearly 50′ in diameter.
H.VI 37 Draconis	17	58·6	+66	38	Bright planetary.
M.8 Sagittarii	18	01·4	−24	23	Lagoon Nebula. Gaseous. Just visible with naked eye.
NGC 6572 Ophiuchi	18	10·9	+06	50	Bright planetary, between Beta Ophiuchi and Zeta Aquilæ.
M.17 Sagittarii	18	18·8	−16	12	Omega Nebula. Gaseous. Large and bright.
M.11 Scuti	18	49·0	−06	19	Wild Duck. Bright open cluster.
M.57 Lyræ	18	52·6	+32	59	Ring Nebula. Brightest of planetaries.
M.27 Vulpeculæ	19	58·1	+22	37	Dumb-bell Nebula, near Gamma Sagittæ.
H.IV 1 Aquarii	21	02·1	−11	31	Bright planetary near Nu Aquarii.
M.15 Pegasi	21	28·3	+12	01	Bright globular, near Epsilon Pegasi.
M.39 Cygni	21	31·0	+48	17	Open cluster between Deneb and Alpha Lacertæ. Well seen with low powers.

PART FOUR

Miscellaneous

Some Recent Books

The Exploration of the Universe (*Brief Edition*), by George Abell (Holt, Rinehart and Winston, New York and London, 1969). As this book runs to 478 pages, it is hardly 'brief', but it provides a comprehensive account of modern astronomical work, and is thoroughly to be recommended.

Astronomy for Beginners, by Henry Brinton (Pelham Books, London 1970). A general outline, very clearly written, and with the emphasis on amateur work.

Sundials, by F. Cousins (Baker, London 1969). A detailed account of all aspects of the subject.

The Old Moon and the New, by V. A. Firsoff (Sidgwick & Jackson London 1969). A discussion of modern problems of the Moon, written by an acknowledged expert. It is highly informative, and in places controversial.

The High Firmament, by A. J. Meadows (Leicester University Press, Leicester 1969). Not strictly an astronomical book, but it traces the influence of astronomy upon literature through the ages, and contains comments and information not to be found elsewhere in book form.

Astronomy for O Level, by Patrick Moore (Duckworth, London 1970). A textbook for those who wish to take the O level G.C.E. examination which is now part of the official syllabus.

Edmond Halley, by C. A. Ronan (Macdonald, London 1969). An account of the second Astronomer Royal, whose reputation is somewhat overshadowed by that of Newton, but who made many fundamental contributions to science on his own account.

Our Contributors

HENRY BRINTON, a regular contributor to the *Yearbook*, is an amateur astronomer who has his private observatory at Selsey in Sussex. He has written on social subjects, and is a member of the Regional Hospital Board; he is also an historian, and is author of a well-known book, *The Context of the Reformation.*

R. A. G. GULLEY lives in Beckenham. He is not an amateur astronomer in the accepted sense of the term, but the form of observatory which he has designed, and which is described in this *Yearbook*, has been widely followed.

W. J. LEATHERBARROW, B.A., is known as an observer of the Moon, and has published many research papers on the subject. His degree is in Russian, and he is now a lecturer in this language.

HOWARD MILES, M.SC., is Director of the Artificial Satellite Section of the British Astronomical Association, and Lecturer in Mathematics at the Lanchester College of Technology, Coventry. He has contributed articles to many previous *Yearbooks.*

IAIN NICOLSON, B.SC., is Lecturer in Astronomy at the Hatfield Polytechnic; he is a graduate of St Andrews University. His main astronomical research has been on the subject of interstellar matter.

GILBERT E. SATTERTHWAITE was formerly a professional astronomer at the Royal Greenwich Observatory, specializing in positional astronomy. He is now on the staff of the Geological Society, and is Director of the Saturn Section of the British Astronomical Association.

Astronomical Societies

The advantages of joining an astronomical society are obvious enough. Full information about national and local Societies was given in the 1966 *Yearbook*; a condensed list, suitably brought up to date, is given below.

Name	*Secretarial Address*	*Yearly Subscription* §=members under 18, or 'juniors'	*Meeting Time and Place*
British Astronomical Association	Burlington House, Piccadilly, London, W.1. (Miss Lydia A. Brown)	65*s* (§50*s*)	Burlington House, Piccadilly Last Wed. each month (Oct-June)
Irish Astronomical Society:			
Belfast Centre	35 Ardenvohr Road, Belfast (D. Beesley)	20*s* (§10*s*)	Fortnightly, Queen's University, Belfast
Dublin Centre	St Fintan's Cottage, Carrickbrack Road, Sutton, County Dublin (F. Murphy)	20*s* (§10*s*)	Fortnightly University College, Earlsfield Terrace, Dublin
Armagh Centre	The Royal School, Armagh (J. Perrott)	20*s* (§5*s*)	Monthly The Planetarium, Armagh
North-West Centre	Magee University College, Londonderry (Professor W. J. Guthrie)		
Aberdeen and District Astronomical Society	14 Abbotshall Gardens, Cults, Aberdeen (W. P. Cooper)		Robert-Gordon's Institute of Technology St Andrew Street, Aberdeen
Altrincham and District Astronomical Society	10 Delamere Road, Gatley, Cheadle, Cheshire (Colin Henshaw)	5*s*	Park Road Library, Timperley 1st Friday of each month 7.30 p.m.
Aylesbury Astronomical Society	9 Elm Close, Butler's Cross, Aylesbury (N. Neale)	20*s*	As arranged
Birmingham Astronomical Society	17 Hannafore Road, Edgbaston, (W. E. Marsh)	20*s* (§5*s*)	Birmingham and Midland Institute Monthly
Bridgwater Astronomical Society	8 Dunkery Road, Bridgwater, Somerset	10*s*	The Fountain Inn, Bridgwater, 1st Friday in each month
Bristol Astronomical Society	10 Sherbourne Street, St. George, Bristol 5 (S. J. Brewer)	20*s*	Lecture Theatre, Bristol University 3rd Friday each month, Sept.-May
Caithness and Dounreay Astronomical Society	Room 31, Ormlie Lodge. Thurso, Scotland (Miss M. J. A. Clark)	20*s*	Fortnightly
Cambrian Astronomical Society	43 Heol Chappell, Whitchurch, Cardiff (G. Stokes)	15*s* (§7*s* 6*d*)	Every 3rd week, 7.30. 38 Park Place, Cardiff

Name	*Secretarial Address*	*Yearly Subscription* §=members under 18, or 'juniors'	*Meeting Time and Place*
Cambridge Astronomical Society	5 Haggis Gap, Fulbourn (S. R. Whistler)	21*s* (§7*s* 6*d*)	7 Brooklands Avenue, Cambridge 2nd Mon. each month, Oct.–July
Chester Society of Natural Science, Literature and Art	8 Guy Lane, Waverton, nr. Chester (Mrs. N. Hoskyns)	—	Grosvenor Museum, Chester Fortnightly
Chesterfield Astronomical Society	Hilltop Cottage, Gallery Lane, Holymoorside, Chesterfield (Mrs. R. C. Naylor)	20*s* (§10*s*)	Barnett Observatory Newbold Each Friday
Clackmannanshire Astronomical Society	9 Deer Park, Sauchie, Alloa (J. Cluckie)	20*s*	St Mary's School, Alloa. Monthly, 3rd Friday Sept.–May
Cleethorpes Astronomical Society	95 Sandringham Road, Cleethorpes, Lincolnshire (W. S. Cobley)	£1 (10*s*§)	Dolphin Hotel, Cleethorpes, Monthly
Crawley Astronomical Society	Crawley College of Further Education, Sussex (F. D. Cooper)	7*s* 6*d*	Crawley College of Further Education Monthly
Crayford Manor House Astronomical Society	Manor House Centre, Crayford, Kent (R. H. Chambers)	None	Manor House Centre, Crayford Monthly during term-time
Dundee Astronomical Society	4 Finlaggan Place, Dundee Scotland (D. Gavine)	10*s* (§5*s*)	Mill's Observatory Dundee Fortnightly in the winter
Eastbourne Astronomical Society	80 Ringwood Road, Eastbourne, Sussex (W. O. Tutt)	21*s* (10*s*§ 6*d*)	As arranged Monthly
East Lancashire Astronomical Society	95 Accrington Road, Blackburn (L. Willan)	20*s* (§7*s* 6*d*)	Longridge Observatory Preston
Astronomical Society of Edinburgh	126 W. Saville Terrace, Edinburgh 9, Scotland (N. G. Matthew)	20*s*	Calton Hill Observatory, Edinburgh Monthly
Ewell Astronomical Society	11 Elmwood Drive, Ewell, Surrey (J. Bentley)	20*s* (§10*s*)	Pitt House, Ewell, Surrey 2nd Tuesday of each month
Fellowship of Junior Astronomers, Edinburgh	58 Ogilvie Terrace, Edinburgh 11, Scotland (Miss Edith McLean)	7*s* 6*d*	Calton Hill Observatory Edinburgh 2nd Sat. each month, Sept.–June
Fylde Astronomical Society	115 Abercrombie Road, Fleetwood, Lancs (P. P. Cuffe)	10*s* (§5*s*)	Nautical College, Fleetwood 1st Thursday of each month, Sept.–May inclusive
Astronomical Society of Glasgow	164 Mugdock Road, Milngavie, Glasgow, Scotland (N. M. Orr)	10*s*	Roy. Coll. Science and Tech., Glasgow 3rd Thur. each month, Sept.–April
Herschel Society	35 Kendal Drive, Slough (C. Wise)	—	(To be announced)
Junior Astronomical Society	—	—	Caxton Hall, Quarterly
Leeds Astronomical Society	Maths. Dept., The University, Leeds 2 (B. L. Meek)	10*s* (§5*s*)	Leeds University Six annually

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Leicester Astronomical Society	49 Bringhurst Road, Leicester (C. Shuttlewood)	21*s* (§7*s* 6*d*)	Leicester Museum and Art Gallery Monthly
Lincoln Astronomical Society	344 Brant Road, Lincoln (P. Hammerton)	20*s* (§5*s*)	Lincoln YMCA Hall 1st Tue. each month
Liverpool Astronomical Society	135 St Michael's Road, Great Crosby, Liverpool 23 (J. E. Abrahams)	15*s* (§5*s*)	Royal Institution, Liverpool Monthly
Loughton Astronomical Society	Aldersbrook House, Romford Road, Manor Park E12 5LN (D.E. Brede)	30*s* (§20*s*)	Loughton Hall, Rectory Lane, Loughton, Essex Thursdays, 8 p.m.
Luton Astronomical Society	25 Braithwaite Court, Luton (N. A. Rumble)	20*s* (§ free)	Last Friday each month
Maidenhead Astronomy Group	129 Fane Way, Maidenhead, Berkshire (S. A. H. Roper)	10*s*(§2*s* 6*s*)	Maidenhead Grammar School Once every 3 weeks
Manchester Astronomical Society	Cragside, Cliff Avenue, Summerseat, Bury (Alan Whittaker)	20*s* (§10*s*)	Godlee Observatory, Manchester 1 Weekly
Mansfield and District Astronomical Society	6, Shelton Close, Fairholm Estate, Mansfield, Notts.	10*s* (§5*s*)	(To be announced) Last Monday of each calendar month
Newcastle-on-Tyne Astronomical Society	30 Kew Gardens, Whitley Bay, Northumberland (G. E. Manville)	20*s*	Botany Lecture Theatre Newcastle University Monthly, Sept.–April
Newtonian Observatory Astronomical Society	101 Ardingly Drive, Goring-by-Sea, Worthing, Sussex (G. L. Boots)		
North Dorset Astronomical Society	The Pharmacy, Stalbridge, Dorset (F. Coward)	—	Charterhay, Stourton Caundle, Dorset Quarterly
Nottingham Astronomical Society	18 Naseby Close, Heathfield, Nottingham (C. Swift)	25*s*	Monthly
Oxshott Astronomical Group	Norman Cottage, Pond Piece, Sheath Lane, Oxshott, Surrey (E. H. Noon)	10*s*	Oxshott Village Centre 1st Wed. each month Sept.–May
Paisley Astronomical Society	14 Cheviot Avenue, Barrhead, Glasgow (Mrs. J. Holms)	20*s* (full), 10*s* (associate) (half subscription for those under 21)	Coats Observatory, 49 Oakshaw Street, Paisley Monthly
Plymouth Astronomical Society	5 Woodside, Lipson, Plymouth (Lawrence Harris)		Plymouth College of Technology, Tavistock Road ,Plymouth Monthly
Portsmouth Astronomical Group	52 Denbigh Drive, Fareham, Hampshire (S. W. Hackman)	£3	The Group Observatory
Preston and District Astronomical Society	35 Bispham Road, Carleton, Poulton-le-Fylde, Lancs (C. Lynch)	20*s* (§5*s*)	Chamber of Commerce, 49a Fishergate, Preston 3rd Mon. each month Sept.–May
Salisbury Plain Astronomical Society	St George's Cottage, Orcheston, Salisbury, Wilts. (R. J. D. Nias)	10*s* (§5*s*)	St George's Rectory, Orcheston Quarterly

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Sidereal Society	Flat 2, 11 Wellington Road, Brighton, Sussex (Mrs. M. L. Cohen)	20s (§10s)	6 Brunswick Terrace, Hove, Sussex Each Wed., 730–9.30
Slough Astronomical Society	The Elms, Odds Farm, Green Common Lane, Wooburn Common, High Wycombe, Bucks (E. Shilton)	20s	Monthly
Southampton Astronomical Society	13 Luccombe Place, Shirley, Southampton (F. G. H. Cunningham)	20s (§10s)	Ploygon Hotel, Southampton 2nd Thur. each month Sept.–May
Stoke-on-Trent Astronomical Society	Sundale, Dunnocksfold Road, Alsager, Stoke (M. Pace)	15s	Cartwright House, Broad Street, Hanley Monthly
Swansea Astronomical Society	77 Craiglwyd Road, Cockett, Swansea (R. E. Roberts)	20s	As arranged
Thanet Astronomical Society for Youth	Woodlands, Fair Street, Broadstairs, Kent (Paul Sutherland)	5s	Hilderstone House, Broadstairs, Kent Monthly
Torbay Astronomical Society	4 Heath Rise, Brixham, Devon (Miss A. Longman)	15§ (;5s)	Quay Tor Hotel, Scarborough Road, Torquay Monthly
Waltham Forest and District Junior Astronomy Club	24 Fulbourne Road, Walthamstow, London E17 (B. Crawford)	10s	24 Fulbourne Road, Walthamstow, London E17 Fortnightly (Mondays)
Warrington Astronomical Society	2 Dale Avenue, Appleton, Warrington (B. P. Rees)	20s	Central Library, Museum Street, Warrington, Lancs Monthly, Sept.–May
Warwickshire Astronomical Society	20 Humber Road, Coventry, Warwickshire (R. D. Wood)	80s	20 Humber Road, Coventry Each Tuesday
Wolverhampton Astronomical Society	Garwick, 8 Holme Mill, Fordhouses, Wolverhampton (M. Astley)	20s	38 Tettenhall Road, Wolverhampton Alternate Mon., Sept.–April
West London Astronomical Society	46 Vista Way, Harrow, Middlesex (P. Macdonald)	3s 6d	Monthly (Venue to be announced)
Wyvern Astronomical Society	2 Howcroft, Churchdown, Gloucester (A. F. Edwards)	15s (§5s)	Clubhouse, Churcham Last Friday of each month except Aug.
York Astronomical Society	97 Carr Lane, Acomb, York (R. Emmerson)	20s (§5s)	As arranged Monthly, Sept.–May

It is possible that this list of local societies may not be quite complete. If any have been omitted, the secretaries concerned are invited to write to the Editor (c/o Messrs. Sidgwick & Jackson (Publishers,) Ltd, 1 Tavistock Chambers, Bloomsbury Way, London WC1), so that the relevant notes may be included in the 1972 *Yearbook*.

The front cover illustration is of Bennett's Comet, photographed in April 1970 by M. P. Candy at Perth, Western Australia.

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The Old Moon and the New

V. A. FIRSOFF

with a postscript by Patrick Moore

Ten years ago the moon was a remote celestial object of telescopic study. Today it is rapidly becoming more accessible than some parts of earth. Instruments have been soft-landed on its surface and measurements made, close-up photographic surveys carried out, and in July 1969 the moon's dust was disturbed by man for the first time in its existence.

Yet, despite the enormous strides forward, despite tons of scientific papers, many of the old controversies about the origin, structure and condition of the moon remain unresolved and have been added to in the process of uncompleted evaluation of the vast new observational and photographic material.

Just before the first rocket hit the moon, the author wrote *Strange World of the Moon*, in which he reviewed without fear or favour, the totality of the then available data.

In the *Old Moon and the New* he now re-examines and re-assesses some previous conceptions and suggests new ones.

50s (in U.K. only)

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